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INTEGRATED ANALYSIS TECHNIQUES FOR COMMAND, CONTROL, AND COMMUNICATIONS SYSTEMS (U)

Volume II: Applications (U)

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ALPHATECH, INC.

NOVEMBER 1987

FINAL REPORT FOR AUGUST 1982 - DECEMBER 1985

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SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): TR-293-1 Volume II	5. MONITORING ORGANIZATION REPORT NUMBER(S): AAMRL-TR-87-040
6a. NAME OF PERFORMING ORGANIZATION: ALPHATECH, Inc. — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Harry G. Armstrong Aerospace Medical Research Laboratory - AAMRL/HED
6c. ADDRESS (City, State, and ZIP Code): 2 Burlington Executive Center, 111 Middlesex Turnpike, Burlington, MA 01803	7b. ADDRESS (City, State, and ZIP Code): Wright-Patterson AFB, OH 45433-6573
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F33615-82-C-0509
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62202F	6893	04	63

11. TITLE (Include Security Classification)
INTEGRATED ANALYSIS TECHNIQUES FOR COMMAND, CONTROL, AND COMMUNICATIONS SYSTEMS VOLUME II: APPLICATIONS (U)

12. PERSONAL AUTHOR(S)
Wohl, Joseph G., and Tenney, Robert R.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/82 TO 12/85	1987 November	161

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP
05	08	
17	02	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
system representation, system analysis, performance analysis, Petri nets, queuing networks, hierarchical decomposition

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This is the second volume of a two-volume report describing research on Integrated Analysis Techniques (IAT) sponsored by AAMRL's C^3 Operator Performance Engineering (COPE) Program. As described in Volume I, IAT is a comprehensive framework for the representation and analysis of C^3 systems. This framework consists of:

- A hierarchical method for describing a C^3 system along the four dimensions of process, resource, organization, and goal,
- A mathematical construct for C^3 system modeling (Stochastic, Timed, Attributed Petri nets, or STAPNs), and
- Several C^3 system performance analysis methods (STAPNs, PERT/CPM, and queuing networks).

(Continued over)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Donald L. Monk	22b. TELEPHONE (Include Area Code): (513) 255-8814 — 22c. OFFICE SYMBOL: AAMRL/HED

19. Abstract (Continued)

In this second volume, the results of several trial applications of IAT are reported. These applications were instrumental in evolving the IAT methodology; and also supported the basic validity of the framework. Important lessons learned from these applications indicated that for IAT ever to become a useful analyst's tool, it must be computed-aided.

SUMMARY

This report consists of two volumes: In Volume I, the Integrated Analysis Techniques (IAT) for Command, Control and Communications (C^3) systems, are described, along with the background, concept, requisite methodologies, and recommendations for an automated analyst's aid. In Volume II, the evolution of IAT via successive trial applications to three (C^3) systems is described and the lessons learned are summarized.

This second volume describes in detail the trial applications of the IAT methodology in various stages of its development to three command and control-related systems:

- SIMCOPE, a simulated C^3 subsystem resident at AAMRL;

- the NORAD Missile Warning Center; and

- a generic air defense system.

From each application, certain important lessons were learned and applied in each succeeding application, resulting in the evolution of IAT as described in Volume I.

Both $IDEF_0$ and Data Flow Diagrams were used in these trial applications, and both PERT/CPM and queuing analyses were used to model the C^3 process descriptions. The lessons learned from these applications are summarized at the end of this Volume. Analysis details and guidelines for using the various descriptive methods are included in Appendices.

PREFACE

This work was conducted by personnel of ALPHATECH, Inc. under contract F33615-82-C-0509 with the Harry G. Armstrong Aerospace Medical Research Laboratory, Human Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The methods summarized in this report were developed under program 62202F, Aerospace Biotechnology, Project 7184, Man-Machine Integration Technology.

The authors wish to acknowledge the important contributions to this report made by several people. Dr. Gerald P. Chubb and Mrs. Marta A. Gruesbeck, of the ALPHASCIENCE Division of ALPHATECH, carried out the early trial application of portions of the methodology to the SIMCOPE simulated systems described in Section 2, from which valuable lessons were derived. Dr. Judith R. Kornfeld of ALPHATECH was responsible for the NORAD application described in Section 3 and Appendices B through D. Dr. Richard A. Miller of Ohio State University acted as consultant in analytic methods and prepared parts of Sections 2 and 3 and Appendix A. Finally, Mrs. Patricia A. Vail and Ms. Kendra E. Moore of ALPHATECH were responsible for the Air Defense example in Section 4.

In addition to those individuals mentioned above, the authors would like to thank Mr. James C. Deckert and Dr. Nils R. Sandell, Jr. of ALPHATECH, Mr. Maris Vikmanis and Mr. Donald Monk of AAMRL, and Major Richard Poturalski of Headquarters, Air Force Space Command for their continuing encouragement and support in the face of sometimes seemingly insurmountable obstacles.

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SECTION 1

INTRODUCTION

This volume describes in detail the trial applications of the IAT methodology in various stages of its development to three command and control-related systems:

- SIMCOPE, a simulated C^3 subsystem resident at AAMRL;
- the NORAD Missile Warning Center; and
- a generic air defense system.

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SECTION 2

SIMCOPE APPLICATION

The SIMCOPE facility at AAMRL was chosen as a test case for illustrating the application of preliminary IAT methods. SIMCOPE was selected for several reasons:

1. It approximates the complexity of a node in real-world manned C^3 systems like those at NORAD MWC (even though its scenarios are fictitious).

2. Its operations are neatly circumscribed.

3. It permits the study of human performance within a controlled laboratory environment (that approximates a real-world operational setting).

4. The details of its design and operation can be analyzed and discussed openly (because of its fictitious nature).

The focus of SIMCOPE is on the Missile Warning Officer (MWO), whose main role is to monitor data to detect missile launches that may pose a possible threat. Performance predictions relevant for the validation address questions of system throughput -- e.g., what happens as input message arrivals exceed operator service rates? what operating strategies best handle the work backlog? are there alternative designs that can alleviate the bottleneck?

For using SIMCOPE as a case study to validate IAT methods, several notational formats were required. These are reviewed in the sections that follow.

2.1 OPERATOR SCENARIOS

These specify the tasks and task sequences that MWOs would perform to carry out their responsibilities in a MWC. Subject instructions were developed under the AAMRL COPE Program for this purpose, and are described in ALPHASCIENCE (1984).

2.2 DATA FLOWS (DeMarco)

Because analytic methods like queuing theory require explicit information about data flow, a formalism was needed that would capture this information in SIMCOPE. Of critical interest are the following data flow characteristics:

- Data Stores: sites, temporary repositories of data (e.g., computer files, blackboards, operator displays).

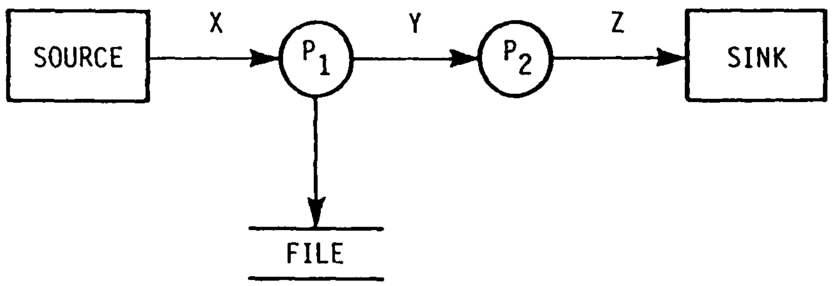
- Sources: points of origin.

- Sinks: points of destination.

- Processes: transformations that map input data to output data.

- Flows: "pipelines" through which packets of information of known composition may flow.

DeMarco data flow diagrams (DeMarco, 1978) provide a simple syntax and semantics for capturing these characteristics. Figure 2-1 describes the components of a DeMarco diagram; Fig. 2-2 presents an example of how these diagrams were used to portray data flow in SIMCOPE. (Detailed discussion and explication of the SIMCOPE example can be found in subsections 2.4 and 2.5, and Appendix E. Table 2-1 lists abbreviations and acronyms used in SIMCOPE.)



COMPONENTS

1. Data flows, represented by labeled arrows; (X,Y,Z)
2. Processes, represented by circles; (P_1,P_2)
3. Files or Data Stores, represented by straight lines; FILE
4. Data Sources or Sinks, represented by boxes.

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Figure 2-1. DeMarco Data Flow Diagram (Example)

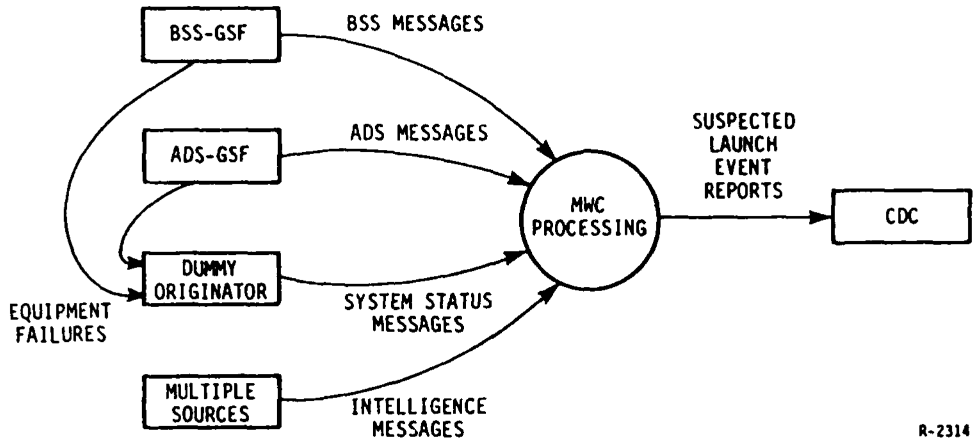


Figure 2-2a. DeMarco Diagram Used in SIMCOPE Validation: Context

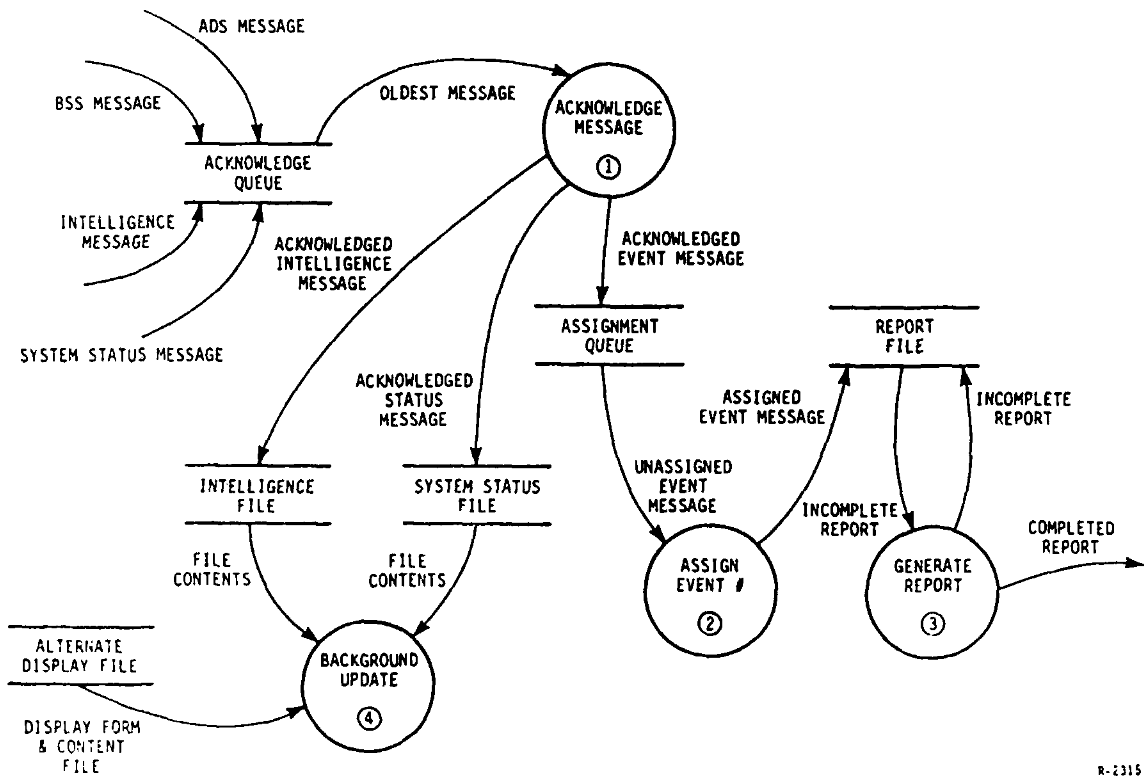


Figure 2-2b. DeMarco Diagram Used in SIMCOPE Validation: Overall Data Flow

TABLE 2-1. LIST OF ABBREVIATIONS AND ACRONYMS USED IN SIMCOPE EXAMPLE

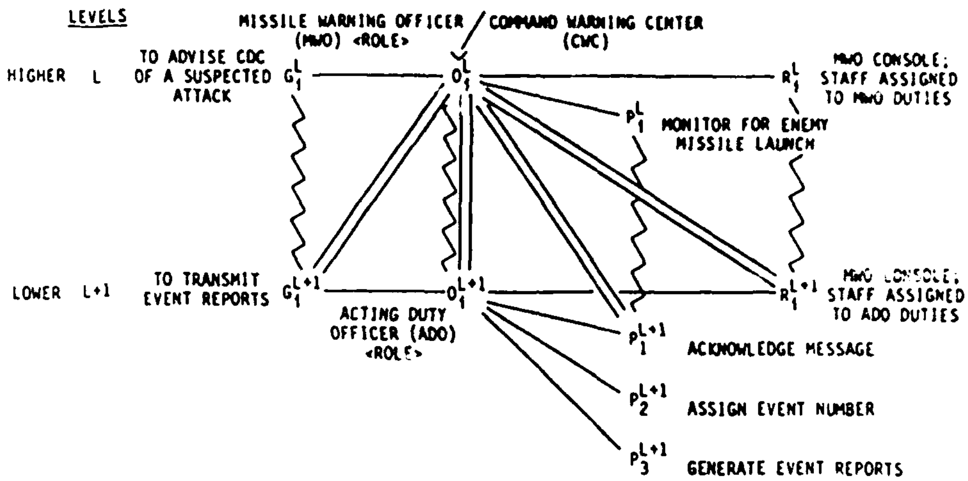
ADS-1	ADS Pass 1 Message
ADS-2	ADS Pass 2 Message
ADS-N	Advanced Detection System-North
ADS-S	Advanced Detection System-South
AGS or ADS-GSF	ADS Ground Support (Facility)
BGS or BSS-GSF	BSS Ground Support (Facility)
BSS	Barrier Surveillance System
BURF or BRF	Back-Up Routing Facility
CDC	Command Defense Center
CWC	Command Warning Center
INT	Intelligence Messages
MWO	Missile Warning Officer
SYS	System Status Messages

ACKNOWL	Acknowledge	Names of Function Keys on Operator Touchscreen
ASSIGN		
BACKSTEP		

AUTO	Names of Mode Controls on Operator Touchscreen
EDIT	

2.3 USE OF FRAME NOTATION

Frames were used to detail aspects of information captured in the data flow diagrams. This was done to facilitate cross-referencing of data elements and provide traceability from data and processes (shown in DeMarco diagrams) back to components of system structure (GOALS, ORGANIZATIONS, PROCESSES, RESOURCES). Figure 2-3 is an example of a PROCESS Frame for the process called "Monitor for Enemy Missile Launch" in the SIMCOPE context; Fig. 2-4 shows the hierarchical decomposition in terms of system structure.



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PROCESS NAME:	MONITOR FOR ENEMY MISSILE LAUNCH
GOAL:	TO ADVISE CDC OF A SUSPECTED ATTACK
ORGANIZATIONAL ELEMENT:	MISSILE WARNING OFFICER (MWO) ... primary responsibility ACTING DUTY OFFICER (ADO) ... delegated responsibility
PARENT PROCESS:	♦
SUB-PROCESSES REQUIRED:	1) ACKNOWLEDGE MESSAGE 2) ASSIGN EVENT NUMBER 3) GENERATE EVENT REPORTS
INPUTS REQUIRED:	MESSAGES - (4 TYPES) 1) INTELLIGENCE 2) SYSTEM STATUS 3) ADS 4) BSS
OUTPUTS:	EVENT REPORTS - (3) 1) ADS1 2) ADS2 3) BSS
MEASURES OF PERFORMANCE:	TIMELINESS ACCURACY
RESOURCES REQUIRED:	MWO CONSOLE STAFF ASSIGNED TO MWO/ADO DUTIES

Figure 2-3. Example of IAT Structural Description and Process Frame for the Process "Monitor for Enemy Missile Launch" (Kornfeld, 1984)

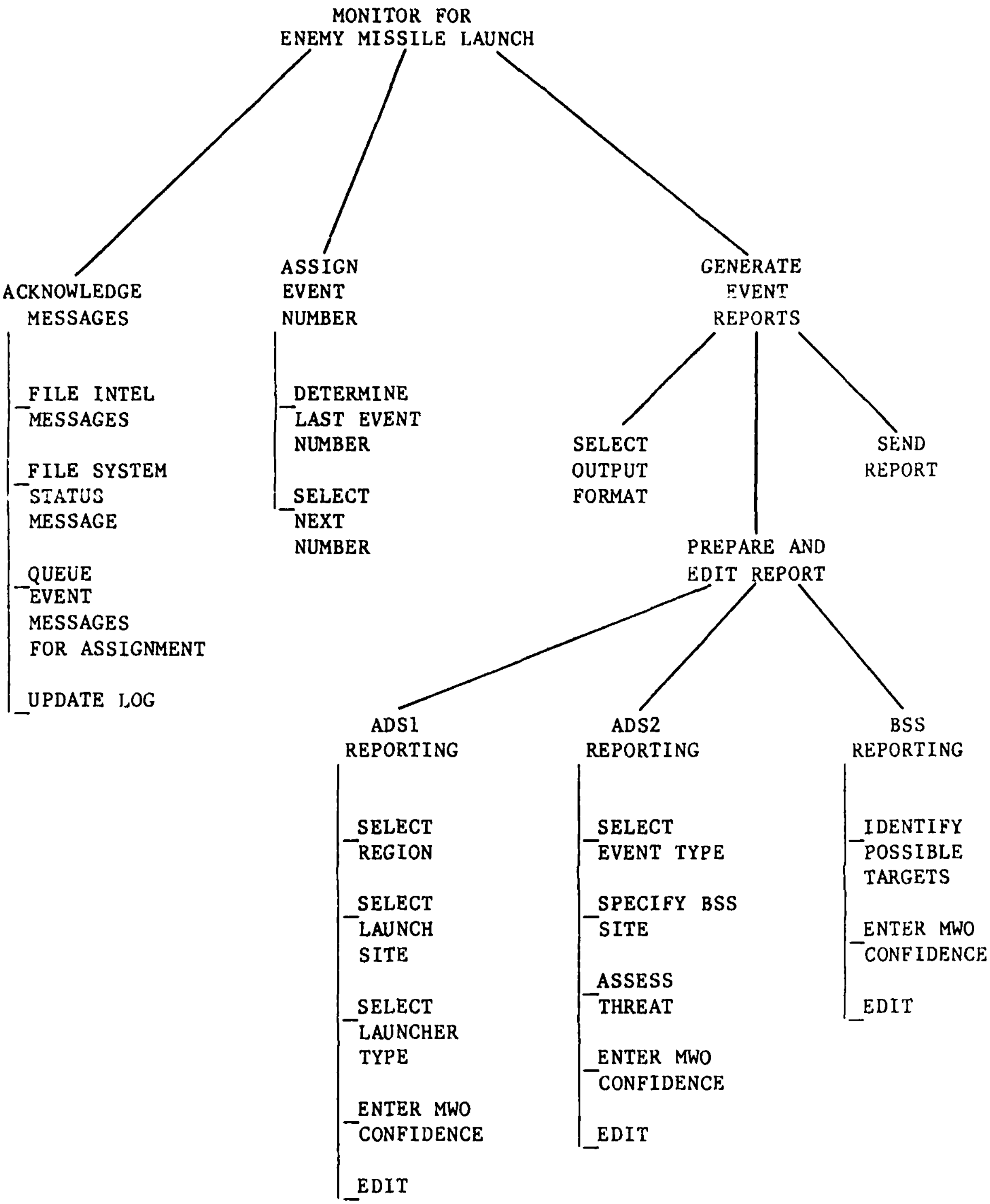

Figure 2-4. Monitor for Enemy Missile Launch: Tree Structure Hierarchy

2.4 QUEUING REPRESENTATION

Describing information about system structure and behavior with the formalisms discussed above made it possible to construct a queuing representation of SIMCOPE. This was a straightforward process to the extent that the data flow and frame analyses revealed specific properties of system behavior that could be captured in a queuing model; viz., SIMCOPE was seen to be:

- highly buffered (i.e., processes were not directly linked but were mediated by queues and file-stores),

- characterized in terms of message-handling, storage, and updating processes.

2.4.1 Identifying Further Information About System Behavior

Figure 2-2a provides the context for further modeling of SIMCOPE using queuing theory approaches. This context diagram makes explicit the various messages that are routed to the Command Defense Center (CDC).

Figure 2-2b describes the system at a high level from the perspective of information flow. Four processes are identified: Numbers 1-3 correspond to the three main functions of the system (Acknowledge Messages, Assign Event-Related Data, Generate Reports); Number 4 describes background updating activities (processing carried out to keep current on intelligence and status information). Only Numbers 1-3 are considered in sufficient detail for building a queuing model of the entire system.

Figures 2-5, 2-6, and 2-7 show the decompositions of SIMCOPE functions, Numbers 1-3, which were introduced at the highest level in Fig. 2-2b.

2.4.2 Insights Obtained From Data Flow Analyses

Figures 2-5 through 2-7 make clear the general flow of activities (message processing) and allow investigators to examine the performance of human agents within the system as a whole. In particular:

- Operator displays function as data stores with respect to message processing.

- Operators directly implement processes Number 1.3 ("Acknowledge Message"), Number 2.2 ("Generate Response"), Number 3.2 ("Select Event"), and Number 3.3 ("Select Data Item"); processes other than those listed here are implemented by computer.

The above-named processes are the primitives of operator tasking in SIMCOPE; any further decomposition of human operator activity would yield only procedural information and not data flow. The methodology used to analyze these processes has thus provided both insight into human/system behavior and has at the same time helped set a practical limit to further decomposition.

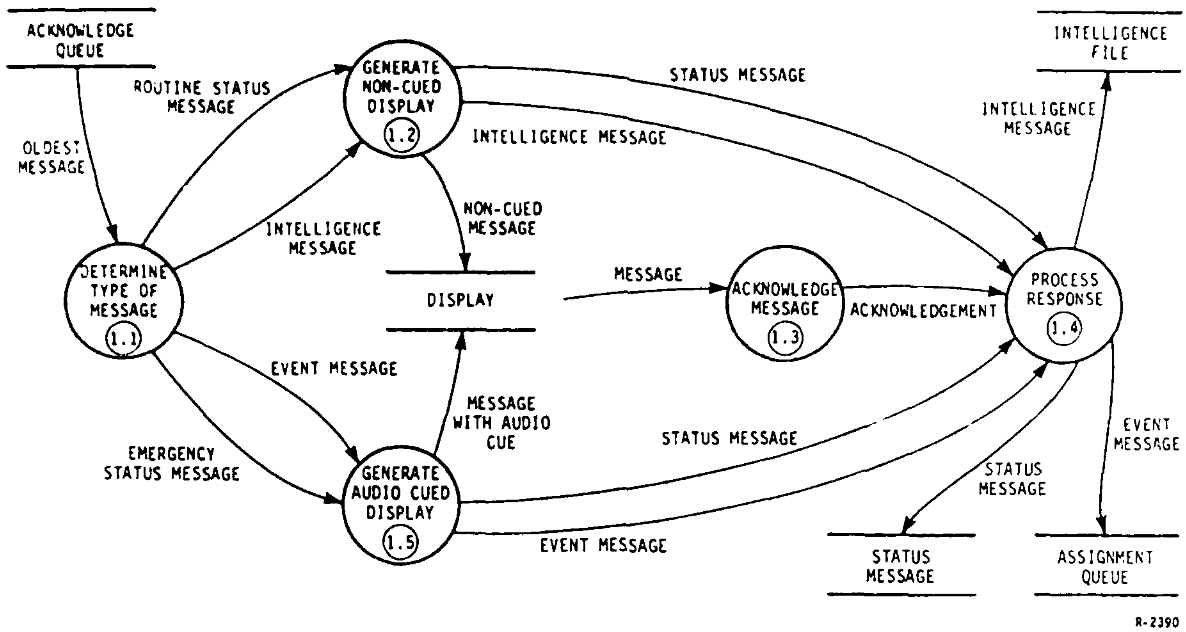

Figure 2-5. The Data Flow Diagram for the Acknowledge Process

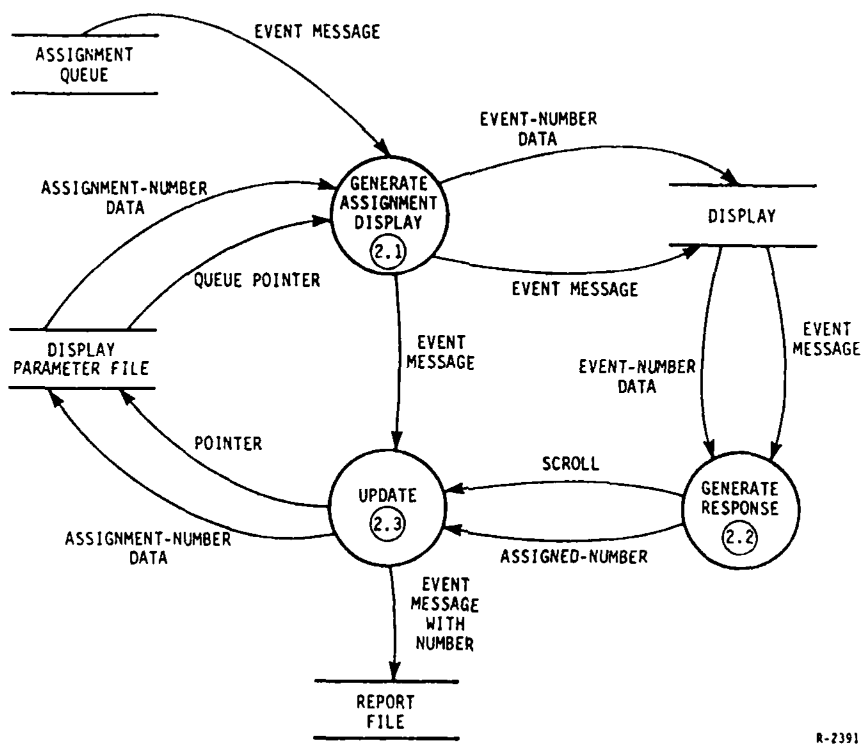

Figure 2-6. The Data Flow Diagram for the Assignment Process

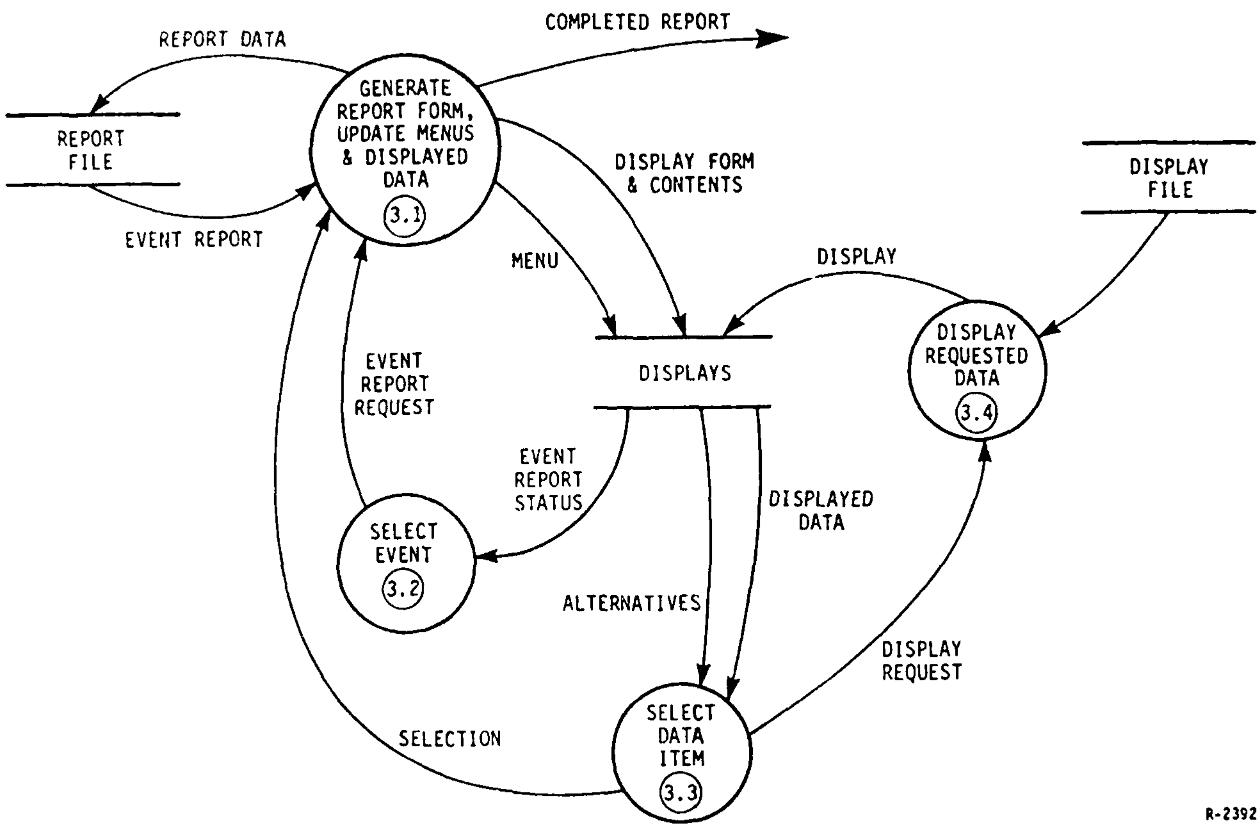

Figure 2-7. The Data Flow Diagram for the Generate Report Process

2.4.3 Constructing the Queuing Representation

The information displayed in Figs. 2-2 through 2-7 was used to derive a queuing representation for SIMCOPE, as presented in Fig. 2-8. This representation is comprised of the following elements:

1. Input source, with messages ("Equipment Status," "Intelligence," and "Suspected Launch Events").

2. A single server (merged from processes 1-3, shown in Fig. 2-2b). (The service facility is located in the Command Warning Center, CWC.)

3. Two output channels ("Equipment Status" and "Intelligence Reports").

4. Two feedback channels (from the "Report" and "Assign" queues back to the CWC).

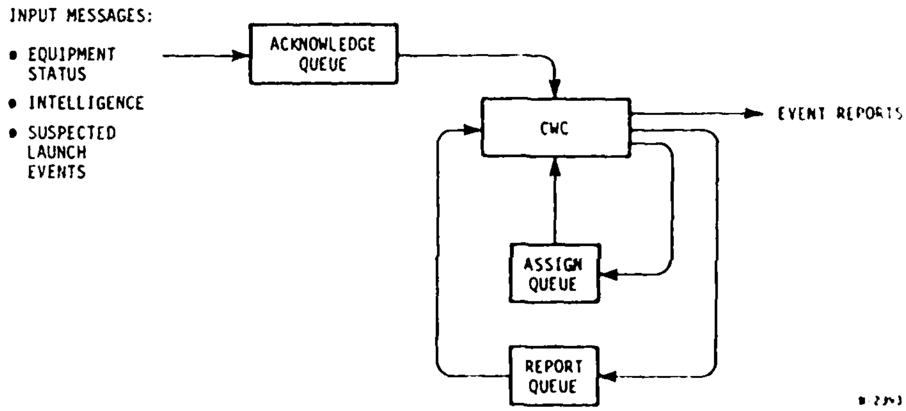

Figure 2-8. The Queuing Representation of SIMCOPE

2.5 THE QUEUING MODEL

2.5.1 Methodology

The following method was used to construct the queuing model for SIMCOPE:

1. Use information derived from operator scenarios (ALPHASCIENCE, 1984), data flows, and frames to characterize message handling and processing -- these activities determine the demand for human and computer resources within the SIMCOPE operational environment.

2. Derive a quantitative description of resource demands associated with workloads, where SIMCOPE workloads are defined by the type, number, and sequence of messages that require processing.

3. Select components of workloads to be characterized. Human operator tasks and task procedures provide a meaningful basis for identifying these components, insofar as task performance can be associated with specific triggering/stopping events ("activations" and "terminations") and completion times.

4. Select features (parameters) for characterizing each component.

5. Use data available from the operational environment via (ALPHASCIENCE, 1984) and from published sources on human performance (Woodson, 1981) to obtain the feature or parameter values for each component.*

*In real-world systems, rather than in simulated environments such as SIMCOPE, this step would constitute workload measurement. Data would be collected while the system is executing. Repeated measurements over time could yield a large collection of multivariate data; exploratory data analysis could then proceed, and empirical distributions and sample moments of each of the parameters might be obtained (Heidelberger and Lavenberg, 1984; Kobayashi, 1978).

Appendix A describes in detail how these procedures were followed to derive quantitative information about human and system performance in SIMCOPE. For the SIMCOPE case, in particular, it was necessary to carry out the steps listed below to characterize workloads in a manner appropriate for obtaining numerical data:

- Identify "scenario-drivers" -- these are factors or events external to the system being analyzed that act as activators or terminators of specific processes in the model. For SIMCOPE, the overall scenario driving the system was described in frames and tree structure notation to show mission events and their impact on human operator workload and task performance.

- State assumptions and describe structure of the queuing model -- viz., characterize message stream, processors, and their associated properties within the SIMCOPE context.

- Develop notations and expressions for arrival and service rates of interest.

- Derive expressions to describe waiting times.

- Estimate delays and queue lengths.

- Determine service rates ("effective rates," given that the same resource must be used in several processes; and task-specific rates, for cases in which resource attention is devoted to a particular task).

2.5.2 Quantitative Results and Their Implications

Workload and Capacity

Since the workload imposed on human operators is a critical factor in allocating tasks in manned C^3 systems, the quantitative estimates and characterization of workload in SIMCOPE should be viewed as significant inputs for improving human and system performance. As part of the queuing theory approach to modeling SIMCOPE, the following features were analyzed and their associated values obtained:

1. Time required for performing single tasks and a series of tasks.

2. Extent to which operators were (assumed to be) mentally or physically busy.

3. Rates for making decisions and processing information.

Determining values for these human (operator)-oriented measures provides analysts and planners with information they need to examine system- or installation-oriented measures such as throughput and utilization, both of which can indicate the efficiency, or degree of productivity, a system provides.

Redesign Issues

Managing existing systems efficiently and planning adequately for future systems requires that the following be done:

1. Identify current performance problems and correct them (e.g., by load shedding or workload balancing).

2. Identify potential future performance problems and prevent them (e.g., by upgrading system resources in a timely manner).

The modeling work presented in Appendix A, subsections A-4 and A-5, yields results relevant to both of the tasks mentioned above. In particular, system bottlenecks were identified for the SIMCOPE environment (e.g., acknowledging audio-cued arriving messages).*

Using queuing analysis techniques to identify bottlenecks becomes useful to supervisors and planners because it could allow them to explore effects of changing particular types of input (e.g., audio-cued arriving messages as opposed to non-cued) on specific tasks facing human operators (acknowledging certain kinds of messages).

Potential benefits of adding one or more operators could also be examined, given the analysis in Appendix A, subsections A.3.2 - A-4, by adjusting the appropriate service time parameters.

Finally, the close analysis of operator tasks required for the SIMCOPE modeling revealed that the CRT display design directly affected service times. The display could be redesigned to facilitate human performance in scanning tasks (e.g., using reverse video, blinking, or other visual contrasts to highlight events under consideration, and thereby reduce effective search time).

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*By "bottleneck," we refer to a resource or service facility whose capacity seriously limits the performance of an entire system. A bottleneck is created at some resource when the job traffic ("workload") to that resource approaches the resource capacity (the resource is "saturated" and the level of congestion increases (Kobayashi, 1978)).

SECTION 3

APPLICATION OF IAT TO NORAD CMC MWC/CP

In this section the results of the application of the IAT methodology to the NORAD Cheyenne Mountain Complex (CMC) Missile Warning Center (MWC) and Command Post (CP) are presented. (Appendix B lists acronyms used in this section.) The direction of this activity was focused on the interactions between the MWC and CP in response to a Submarine-Launched Ballistic Missile (SLBM) scenario.*

3.1 FIELD DATA COLLECTION

Information derived from the literature was supplemented by the following sources:

1. Discussion with MWC operations personnel (DO1M/J31M), by telephone and in person, to obtain answers to questions listed in Table 3-7.

2. Task Description Worksheets (TDWs) describing MWC duties, supplied by the Training Development Division (DOTT/J3TT), Directorate of Training, Standards, and Evaluation (DOT/J3T). These TDWs are part of the documentation now in progress to upgrade training materials (to support an Instructional Systems Design (ISD) approach to training program development).

3. SLBM scenario, used by Command Post Training Branch (DO1TOC/J31TOC), Directorate of Training and Exercise (DO1T/J31T). MWC/CP crew members carried out a structured walkthrough of MWC/CP activities, based on this scenario and explained procedures used in the MWC to analyze sensor data and assess threats.

4. Observations of MWC/CP crew, hosted by Directorate of Missile Warning Operations (DO1M/J3SM) and Missile Warning Training Branch (DO1TOM/J31TOM). Crew members were observed and interviewed informally during the following conditions: day-to-day (routine) operations, involving equipment maintenance, logging, etc.; crew change, including preparation and delivery of briefings; SLBM exercise, mirroring activities described in the training scenario.

*M. Vikmanis, private communication to G.P. Chubb, 4 January 1985.

The information collected first-hand from the sources named above was consistent with MWC/CP mission and major functions, as described from the AAMRL literature. Discrepancies were in general due to equipment upgrades, change in crew position names, and facilities arrangements*.

3.2 SCOPE OF THE MODELING

Boundaries of the validation analysis were established as:

INPUT BOUNDARY - messages coming into MWC for processing,

OUTPUT BOUNDARY - dissemination of TW/AA reports to specified subscribers, called "Forward Users."

Figure 3-1 shows the scope of the analysis. Figure 3-2 presents a detail of CP configuration, highlighting crew position roles that figure in the SLBM scenario.

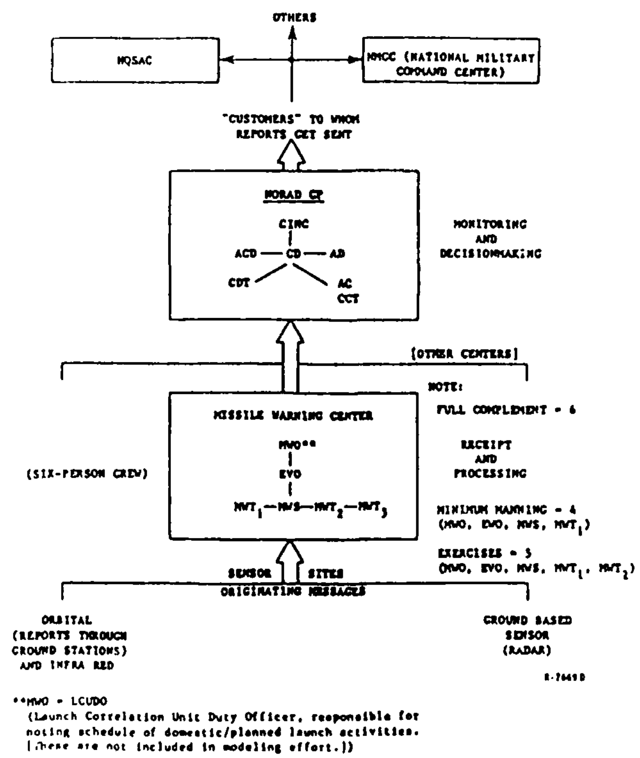

Figure 3-1. High-Level View of MWC/CP Operations**

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*MWC and SPACE were formerly co-located in the CMC.

**Wide arrows indicate the scope of the validation analysis.

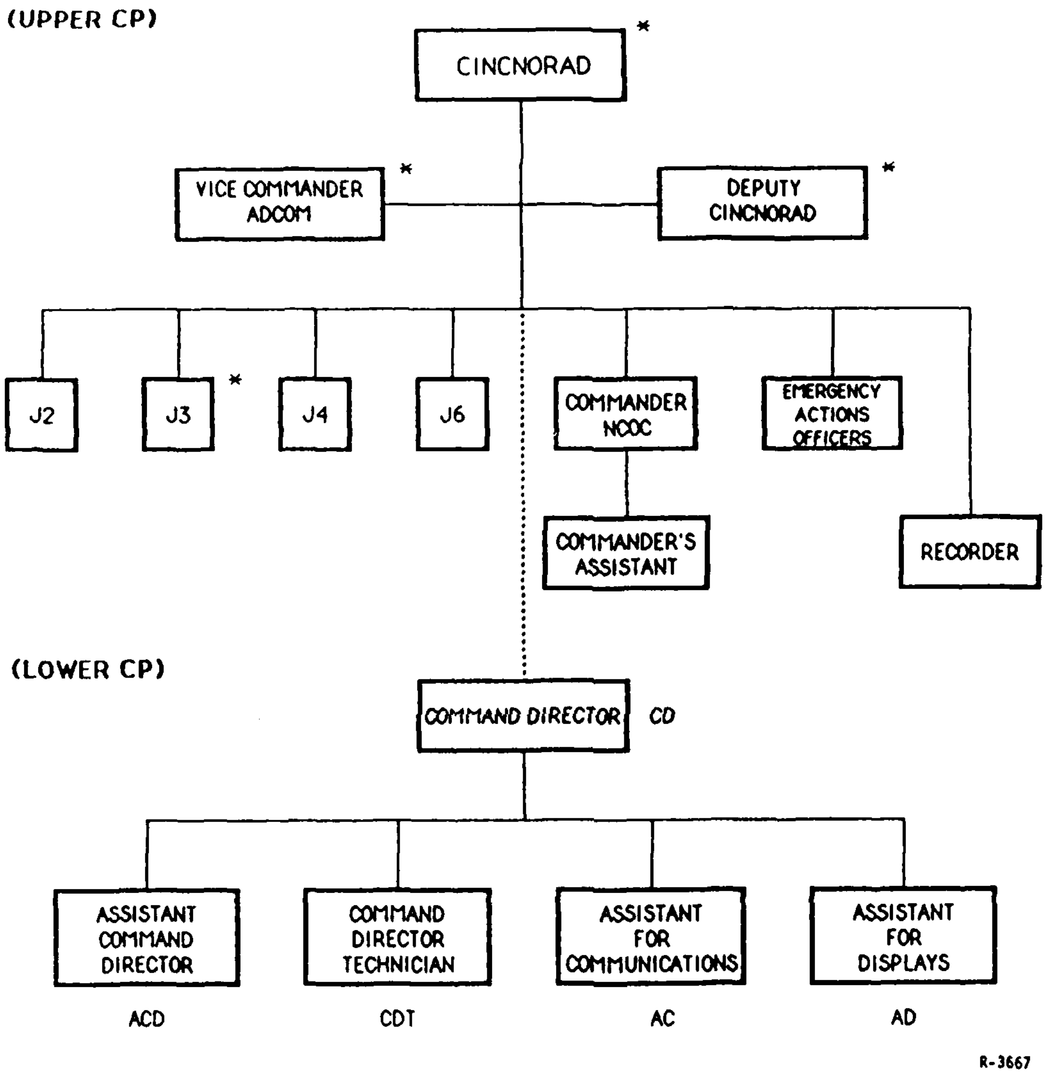

Figure 3-2. Command Post (CP) Organization

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*Assessors: Primary = CINCNORAD
Secondary = Vice Commander ADCOM, Deputy CINC J3 or CD (if none in upper CP available).

3.3 STRUCTURAL MODEL

The SLBM scenario served as the basis for constructing DeMarco data flow diagrams (DFDs) and more detailed flow chart models of human operator and system performance. The results of this modeling are summarized in Figs. 3-3 through 3-11. Explanatory notes and descriptions of human operator tasks and subtasks are provided in Appendix C, where specific TDWs are cross-referenced to activities shown in the flow charts. Appendix D presents a preliminary set of ORGANIZATION frames for the MWC/CP.

3.4 PERFORMANCE MODEL

The purpose of this activity is to convert the descriptive and structural data provided via the data flow diagrams, flow charts, and other notes and training documents into a quantitative model suitable for assessing performance. The primary dimensions of concern are timelines (or delay or throughput) and resource utilization. Earlier work on IAT used queuing network models and associated analysis techniques for this purpose. As will be argued shortly, the MWC/CP system is designed and staffed in such a way that there is very little queuing in the traditional sense of the term. Problems of slow response or delay may well exist, but they can be accounted for with simpler procedures. The structural reasons for these conclusions, as well as illustrations of the performance modeling, are developed below.

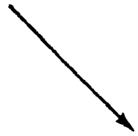
3.4.1 Scope

The focus of the analysis is on the MWC, the CP, and their interactions. The primary processes data flow diagram (Level 0), Fig. 3-5 shows six major processes. One of these, process 1, "Monitor Data and Recognize Event Messages," is performed at the various sensor sites. This process, therefore, will not be directly considered in this analysis. The remaining five processes are carried out jointly by the CP and MWC. Process 6, "Log System Status and Event Data," is a routine function executed after the time-critical activities are completed. For this reason, and for reasons of maintaining simplicity, this process also will not be considered. The modeling, therefore, will focus on the four processes starting with the verification of event reports and ending with TW/AA messages being sent.

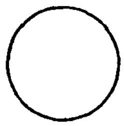
3.4.2 Formulation of a Modeling Approach

Following the same approach that was used with the SIMCOPE example in Section 2, the decomposed data flow diagrams were analyzed for indications of congestion or queuing. The decompositions of processes 2, 3, and 5 shown in Figs. 3-7, 3-8, and 3-9 all reveal numerous data stores. With the possible exception of the "Formatted Messages" store shown on Figure 3-9, there is no indication of a collection or backlog of work requiring processing. By and large, the data stores displayed on these diagrams consist either of short-term "working memory" types of data or archival records. They constitute information available for use rather than work in need of processing.

STANDARD CONVENTIONS:



A directed line represents a flow of information or objects. The arrow indicates the direction of the data flow. The name of the data flow is written through or next to the line.

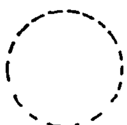


A circle represents a task or process. It identifies a transformation of input data flows into output data flows. A brief descriptive name and a reference number for the process are written inside the circle.

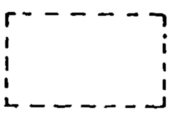
Two parallel lines represent a store of information or objects, irrespective of the storage medium. The store identifies a time delay for its contents. The name of the store is written between the lines.

A rectangle represents an area where data originates or terminates from the point of view of the system study. It identifies a boundary of the system study; the identification of the originator/terminator is written inside the box. Termed "source" or "sink."

NON-STANDARD CONVENTIONS:



A dashed circle represents a process which takes place outside of the Center. No further breakdowns are presented.



A dashed box represents a source or sink outside of the Center.

A dashed arrow represents data being passed outside of the Center.

Figure 3-3. Notes for Data Flow Diagrams

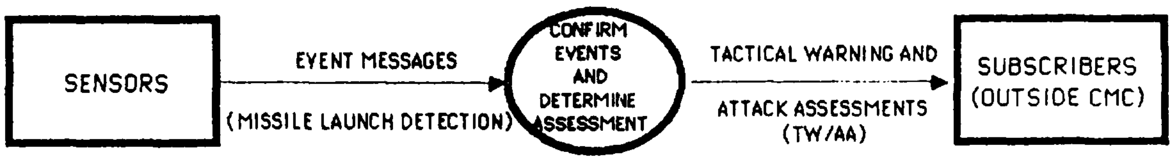


Figure 3-4. NORAD CMC Missile Warning Data Flow (Context)

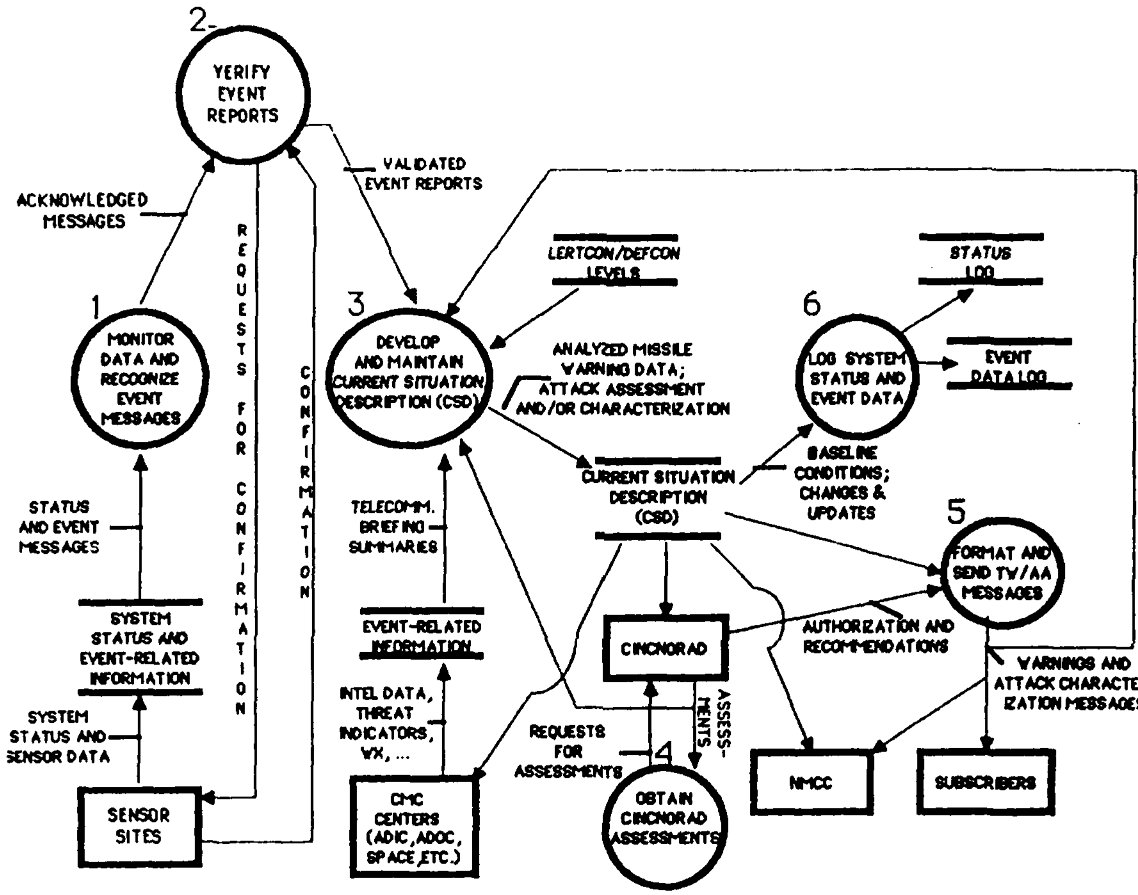


Figure 3-5. MWC/CP Data Flow: Primary Processes (Level 0)

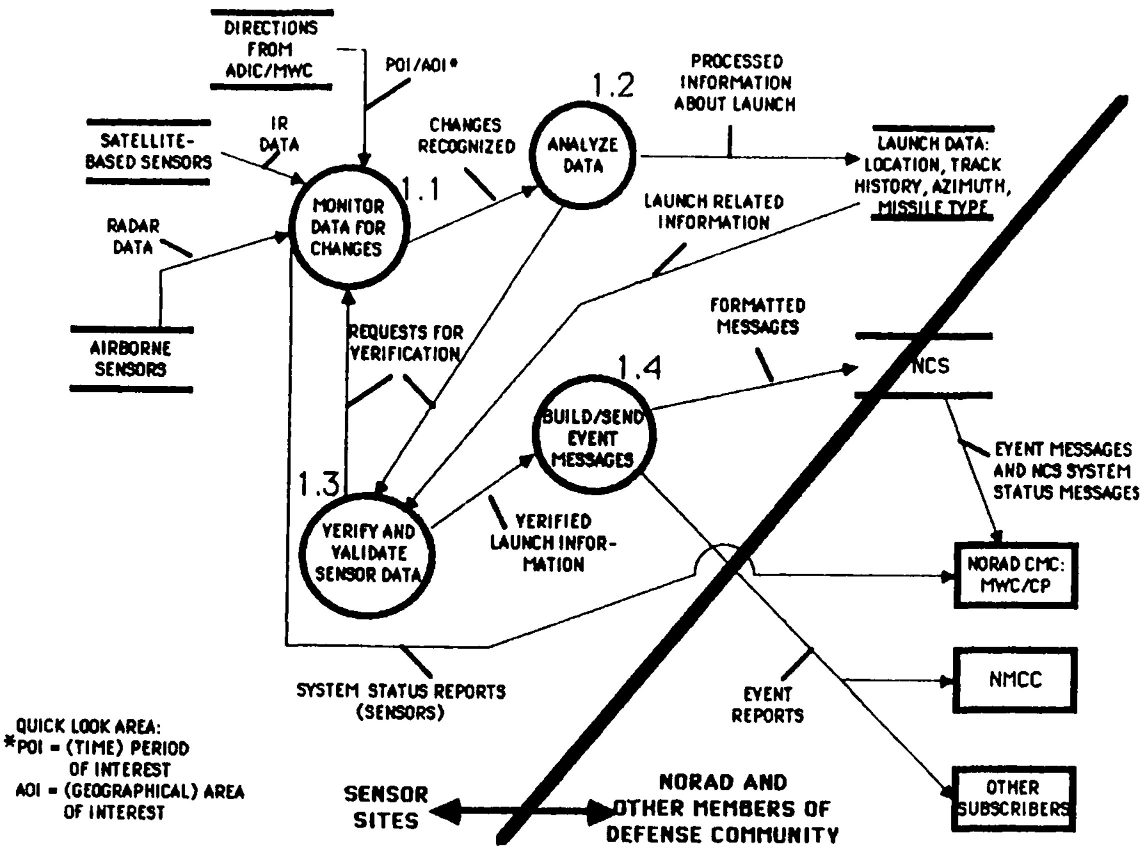


Figure 3-6. Processing Sensor Data: Data Flow Between Ground-Based Stations and NORAD CMC (Level 1)

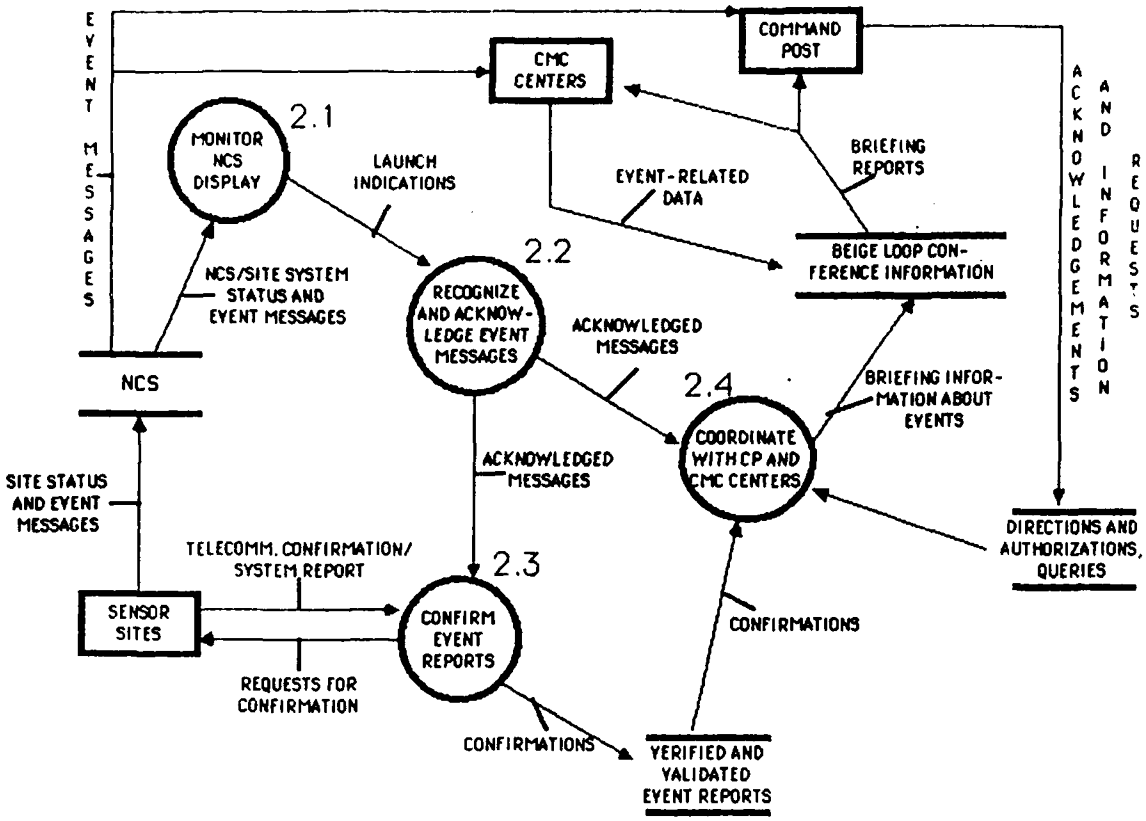


Figure 3-7. Processing Event Reports: MWC Activities (Level 2)

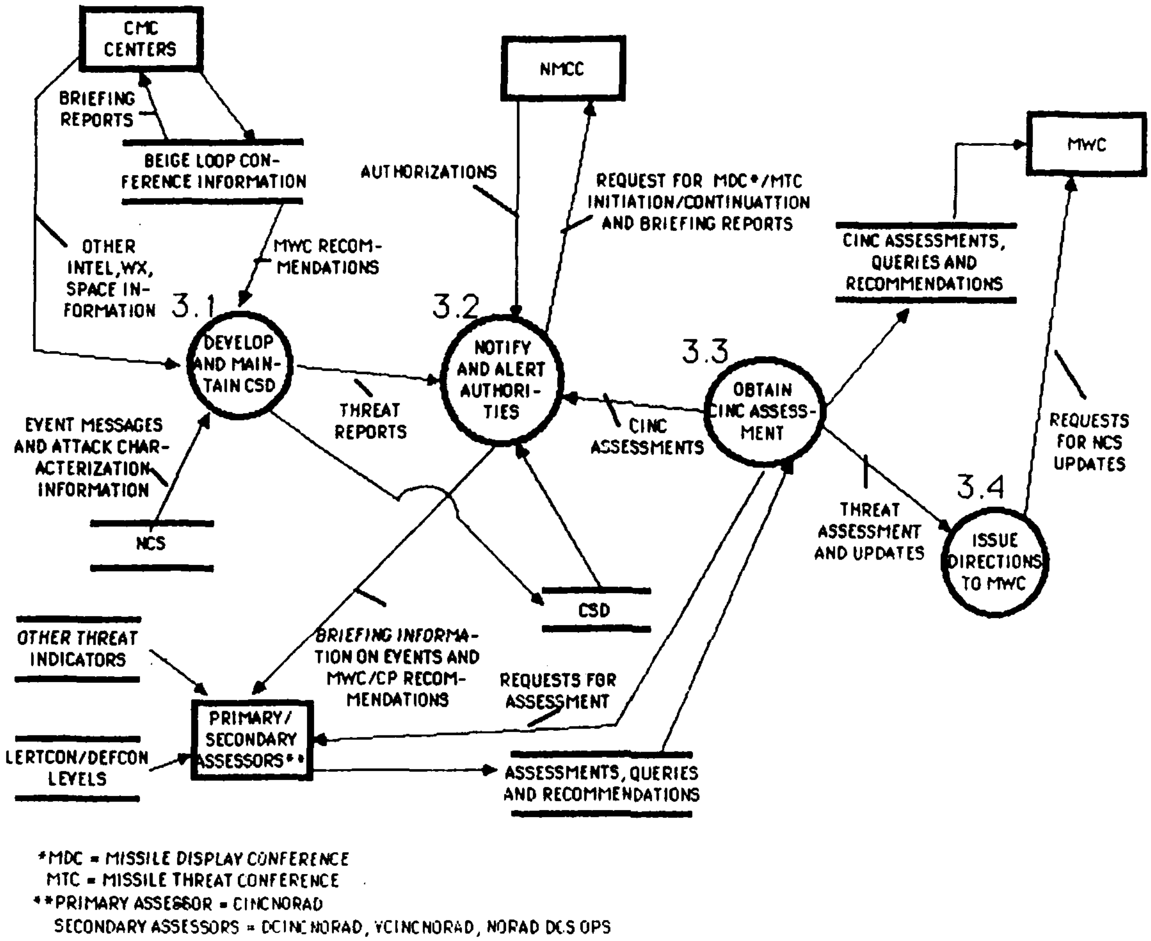


Figure 3-8. Developing Current Situation Description (CSD) and Obtaining CINCNORAD Assessments: CP Data Flow (Level 3)

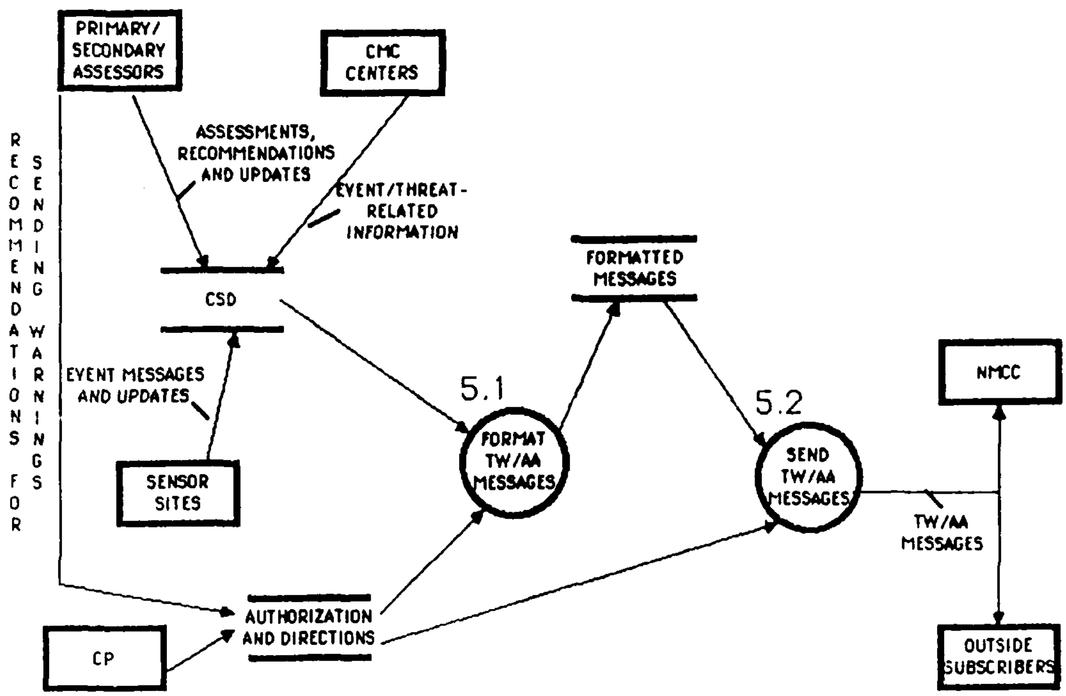


Figure 3-9. Sending TW/AA Messages: MWC Data Flow (Level 4)

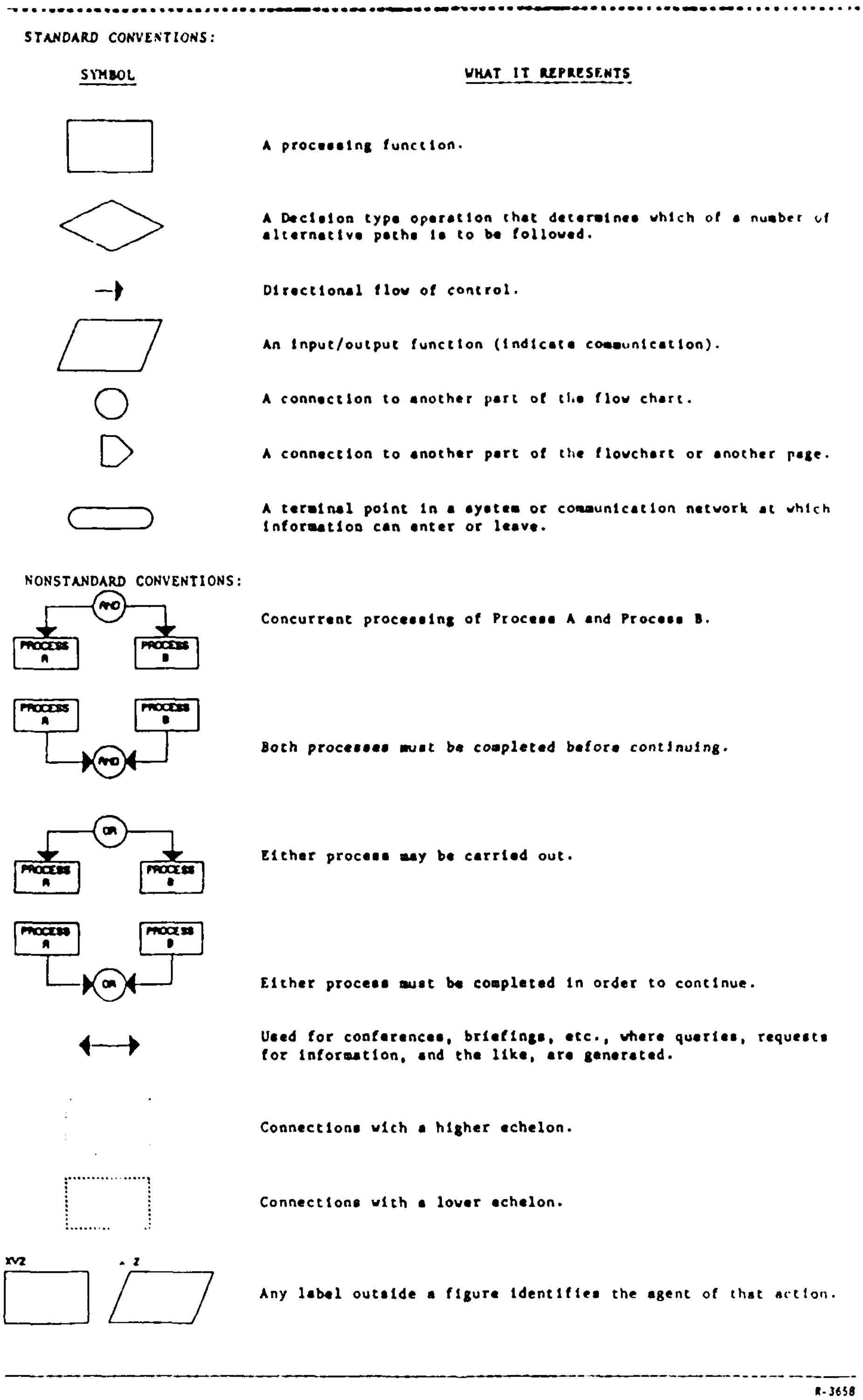


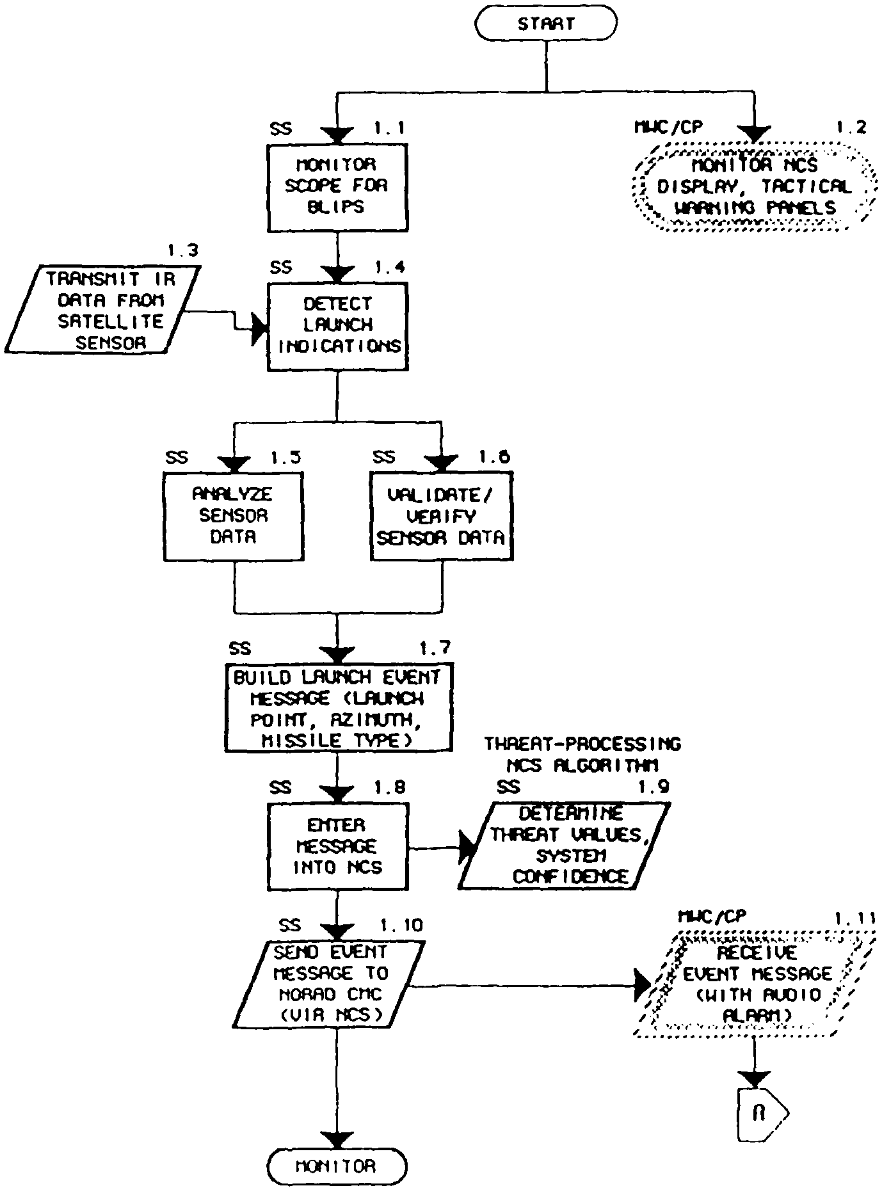
Figure 3-10. Notes for Flow Charts

LEGEND

	SATELLITE/RADAR SENSOR SITE
	MISSILE WARNING CENTER
	COMMAND POST
	OUTSIDE CENTERS
SS	OPERATORS IN TACTICAL OPERATIONS ROOM AT SENSOR SITE
AA	ATTACK ASSESSMENT MESSAGE INCLUDES: CONFIRMATION OF TARGET IDENTIFICATION TARGET TYPE TIME OF IMPACT SITE OF IMPACT
TWM	TACTICAL WARNING MESSAGE
ASSESSMENT_1	SUBSCRIPT "1" INDICATES THE FIRST ASSESSMENT (ACCORDING TO THE SCENARIO).
ASSESSMENT_2	SUBSCRIPT "2" INDICATES THE SECOND ASSESSMENT (ACCORDING TO THE SCENARIO).
NOTE TO *2.29	BEYOND THE SCOPE OF THE ANALYSIS SHOWN HERE. THE SCENARIO ASSUMES A **VALID** SLBM EVENT, WHICH **DOES** CONSTITUTE A THREAT. FALSE EVENTS AND DOMESTIC LAUNCH REPORTS WHICH DO **NOT** CONSTITUTE THREATS ARE NOT CONSIDERED IN THE FLOWCHART MODELING.
NOTE TO *3.24	U200 IS THE INTERFACE TO THE MEBU SYSTEM.

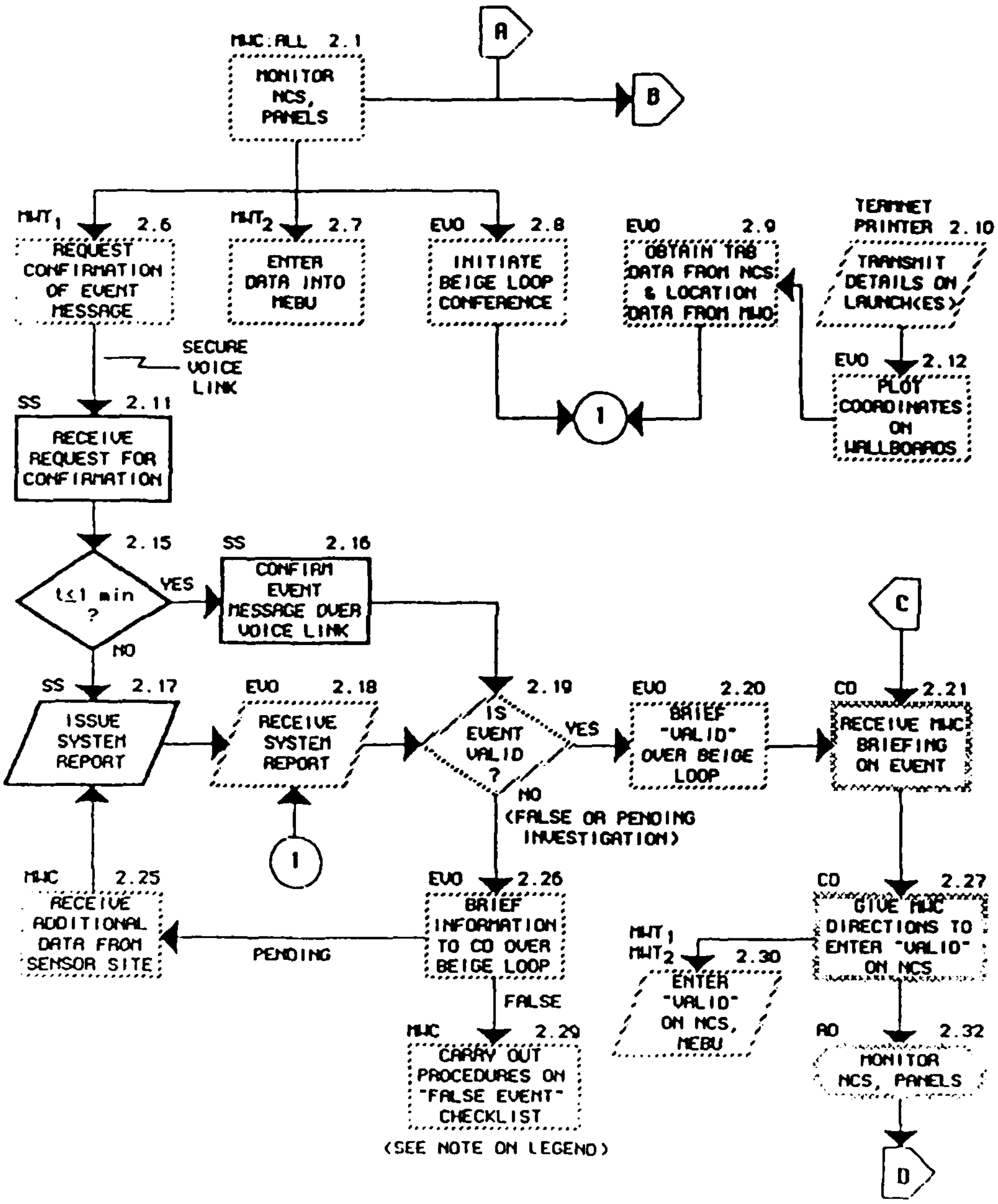
Figure 3-11. Flow Charts for MWC/CP Response to SLBM from Quick Look Area

PROCESSING SENSOR DATA



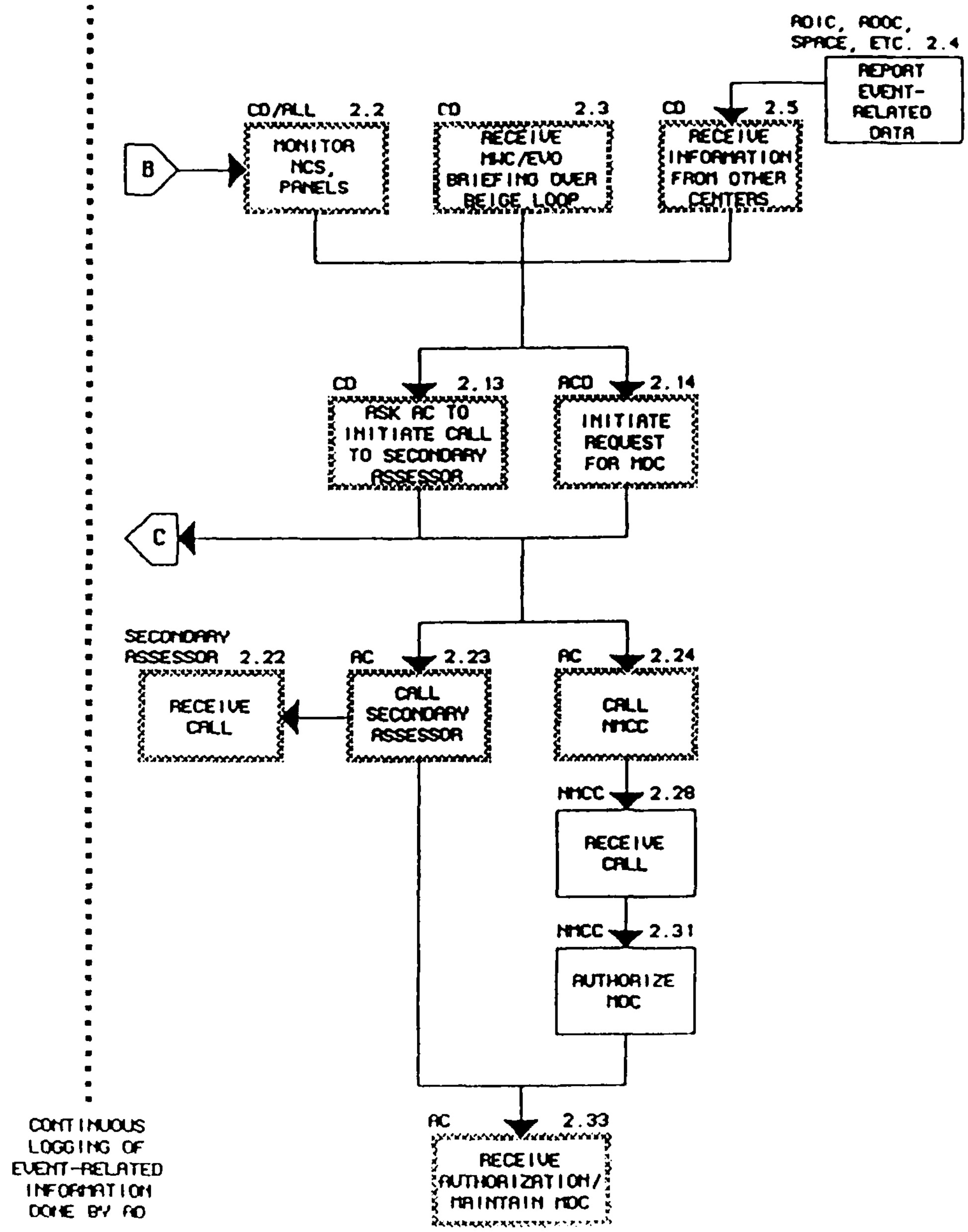
PROCESSING EVENT REPORTS: MWC/CP OPERATIONS

PG 2 OF 7

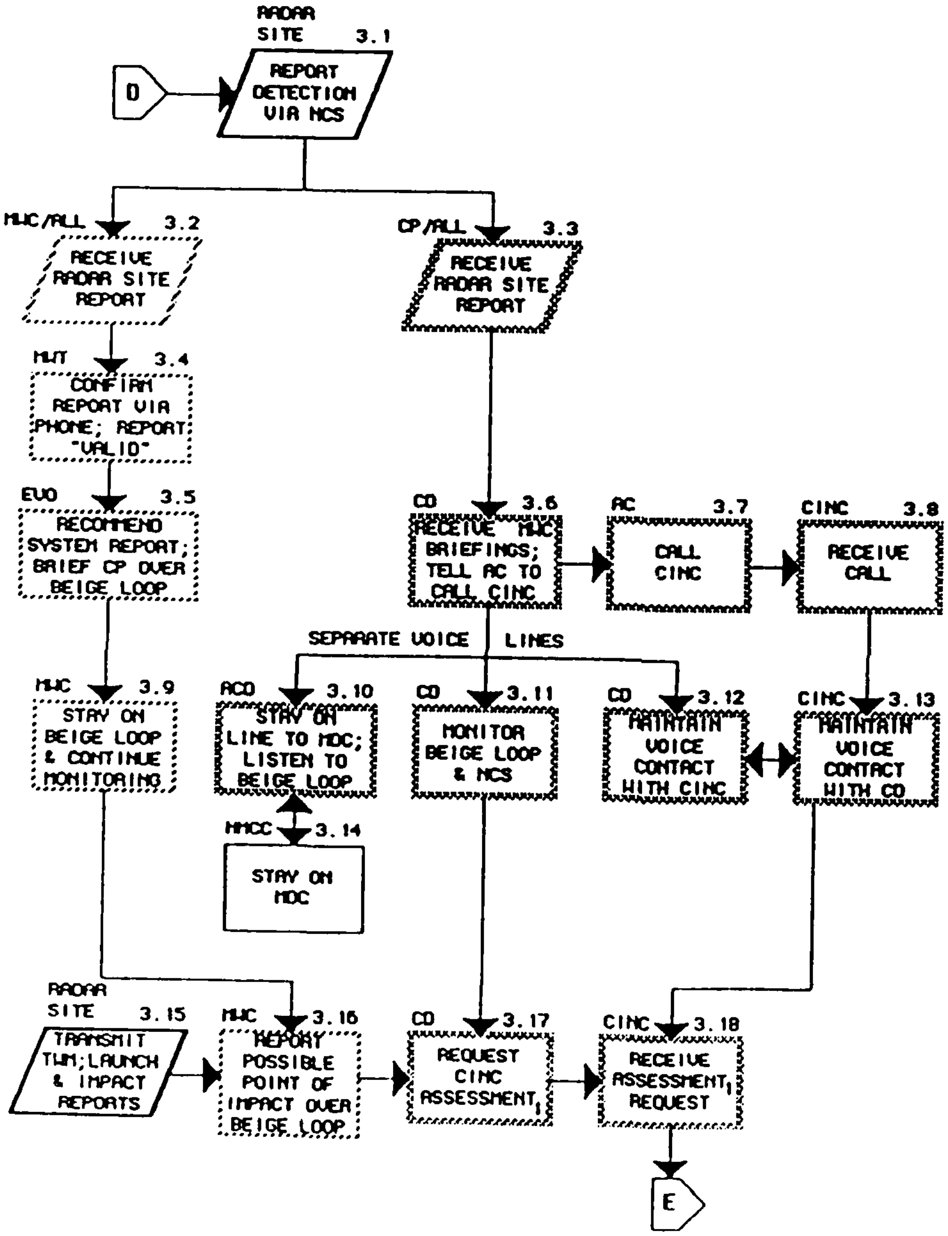


PROCESSING EVENT REPORTS: NWC/CP OPERATIONS

(CONTINUED)

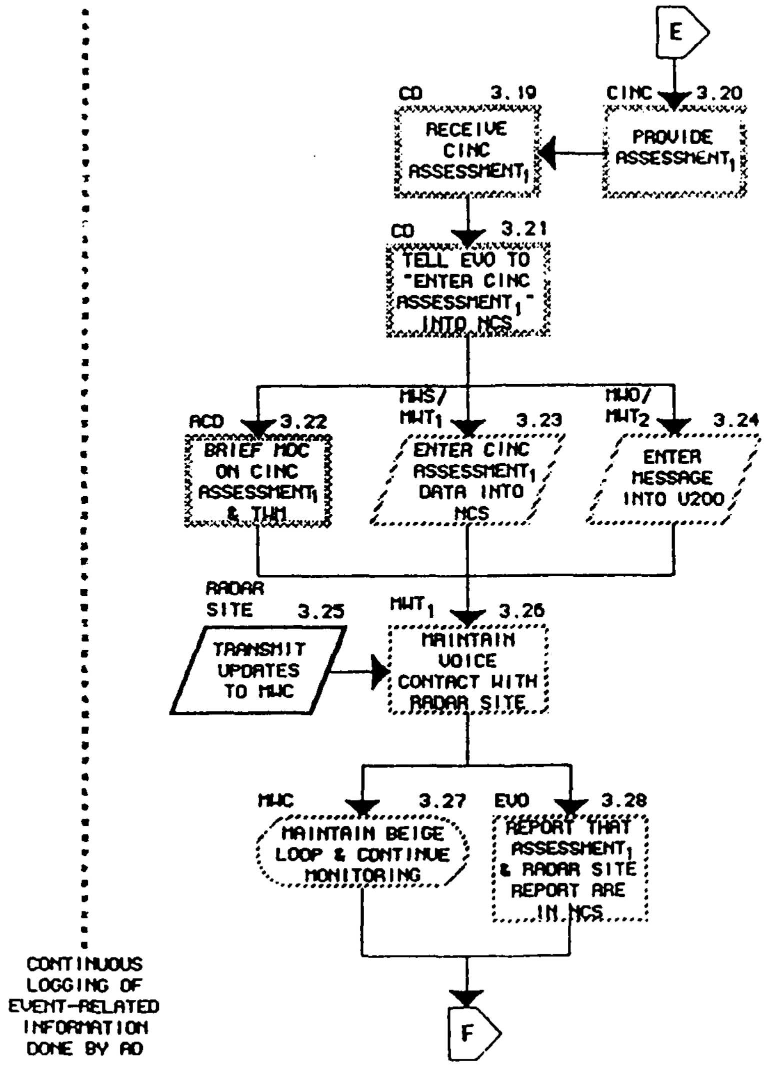


DEVELOPING CURRENT SITUATION DESCRIPTION (CSD) and OBTAINING CINCNORAD ASSESSMENTS: CP DATA FLOW

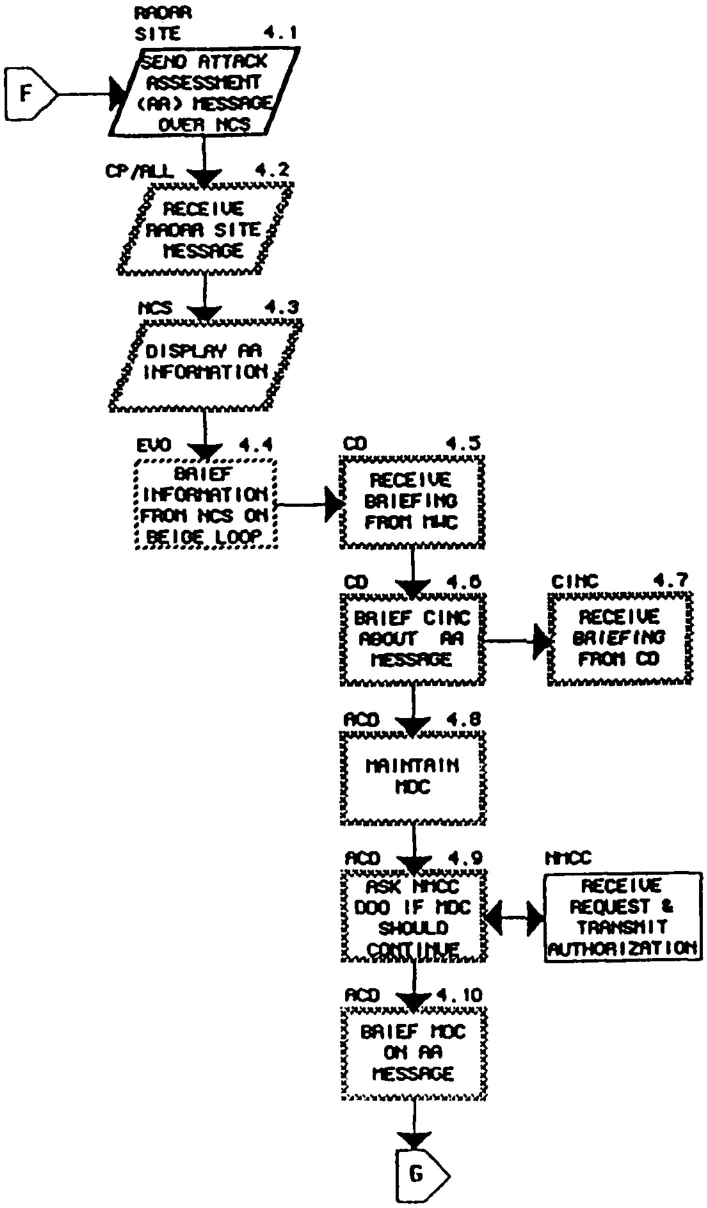


DEVELOPING CSD and OBTAINING CINCNORAD ASSESSMENTS

(CONTINUED)

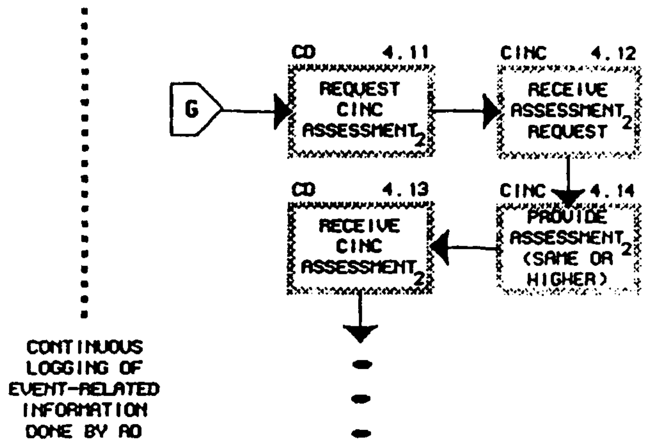


SENDING TW/AA MESSAGES: NWC DATA FLOW



SENDING TW/AA MESSAGES: MWC DATA FLOW

(CONTINUED)



The "Formatted Messages" file could be an exception if it contains a set of messages awaiting service by "Send TW/AA Messages." The Send TW/AA Messages process (process 5.2) is apparently an automated process, so this queue does not influence human performance, although it might have some small impact on overall system throughput.

Since the data flow diagrams provided no evidence of buffering built into the system to accommodate congestion, the flow charts were analyzed for insights into bottlenecks and/or timeliness problems i.e., examined for critical paths. Recall that data flow diagrams, by design, contain no control or procedural information, i.e., they identify processes but not how processing is performed or controlled. The flow charts provide some of this detail.

The timeline associated with the flow charts establishes several time epochs within which the various tasks should be performed. This timeline is based on the SLBM Quick Look scenario and provides a time-available base line. If the time required to perform the necessary tasks exceeds the time available, there can still be a throughput problem (or bottleneck) even though there is no congestion in the form of queues of work.

To gather evidence of such problems, the tasks required of each operator in each time epoch were tabulated. The results are provided in Tables 3-1 through 3-5.

It is clear from these tables that the first time epoch, associated with processing event data, requires a substantial number of tasks, particularly of the EVO. During this phase most of the communications links are established and preliminary data are digested and briefed. Later epochs also involve substantial numbers of tasks, but they consist primarily of briefing information or entering data into the computer systems.

All tasks listed in the tables can be classified as:

1. Configuring a resource.

2. Briefing or otherwise passing information by voice to another user or operator.

3. Enter data into automatic data processing equipment.

It is perhaps significant that there are no judgement tasks (i.e., tasks with open-ended completion times) per se performed by the operators in the system under consideration in this scenario. The task closest to a problem-solving exercise appears to be plotting coordinates, and that obviously is a rather routine activity. It appears, therefore, that good performance in this system depends on the ability to pass along information in a timely fashion. The remaining analysis will, therefore, address the question of whether or not the tasks as described can reasonably be performed in the time available. Since the most demanding time requirements are placed on the EVO during the event processing stage, this stage will be analyzed in detail.

TABLE 3-1. TASKS PERFORMED EPOCH I - PROCESSING EVENT REPORTS

OPERATOR	TASK #	TASK NAME
MWT_1	2.6	Request Confirmation of Event Message
	2.30	Enter Valid on NCS, MEBU
MWT_2	2.7	Enter Data into MEBU
	2.30	Enter Valid into NCS, MEBU
EVO	2.8	Initialize Beige Loop
	2.9	Obtain Data
	2.12	Plot Coordinates
	2.18	Receive System Reports
	2.20 or	
	2.26	Brief Info to CD
CD	2.3	Receive Briefing
	2.5	Receive Briefing from Other Centers
	2.13	Ask ACD to Initiate Call to Second Assessor
	2.21	Receive MWC Briefing
	2.27	Give MWC Direction to Enter Valid
AD	2.32	Monitor NCS, Panels
ACD	2.14	Initiate Request for MDC
	2.23	Call Secondary Assesor
	2.24	Call NMCC
	2.33	Receive Authorization/Maintain MDC

TABLE 3-2. TASKS PERFORMED EPOCH II - DEVELOPING CSD

OPERATOR	TASK #	TASK NAME
MWT	3.2	Receive Radar Site Report
	3.4	Confirm Report via Phone, Report "Valid"
EVO	3.5	Recommend System Report, Brief CD
CD	3.6	Receive Briefings; Tell ACD to Call CINC
	3.11	Monitor Beige Loop and NCS
	3.12	Maintain Voice Contact with CINC
ACD	3.7	Call CINC
	3.10	Stay on line to MDC; Monitor Beige Loop

TABLE 3-3. TASKS PERFORMED EPOCH III - OBTAINING CINC ASSESSMENT

OPERATOR	TASK #	TASK NAME
EVO	3.16	Report Point of Impact over Beige Loop
CD	3.17	Request CINC Assessment
	3.19	Receive CINC Assessment
	3.21	Tell EVO to Enter CINC Assessment into NCS

TABLE 3-4. TASKS PERFORMED EPOCH IV - OBTAINING CINC ASSESSMENTS AND UPDATING CSD

OPERATOR	TASK #	TASK NAME
MWT_1	3.23	Enter CINC Assessment
	3.26	Maintain Voice Contact with Radar Site
MWT_2	3.24	Enter CINC Assessment
EVO	3.28	Report that Assessment and Radar Site Reports are in NCS
ACD	3.22	Brief MDC on CINC Assessment

TABLE 3-5. TASKS PERFORMED EPOCH V - SENDING TW/AA MESSAGES

OPERATOR	TASK #	TASK NAME
EVO	4.4	Brief Info from NCS on Beige Loop
CD	4.2	Receiver Radar Site Message
	4.5	Receive Briefing from MWC
	4.6	Brief CINC
	4.11	Request CINC Assessment
	4.13	Receive CINC Assessment
ACD	4.2	Receive Radar Site Message
	4.8	Maintain MDC
	4.9	Ask if MDC Continue?
	4.10	Brief MDC on AA Message

3.4.3 Analysis of Time-Critical Activities

As shown in Table 3-1 the EVO must initiate the Beige Loop, obtain report data, plot coordinates, receive reports, and brief the CD, all within a very short time. Each task is now considered in detail.

Initiate Beige Loop

According to Task Description Worksheet (TDW) #13 (Appendix C), this task requires three steps:

1. Pick up receiver.

2. Wait for CD to acknowledge.

3. Declare "Missile Initiating."

At this point information is passed to parties on the loop. Estimates of the missile warning personnel suggest that this task takes 5 - 15 seconds. If we assume that this is normally distributed, we can define t_{BL} as the Beige Loop initiating time and

$$t_{BL} \approx N(10, 6.25)$$

i.e., t_{BL} is a normally distributed random variable with variance 6.25. The variance was estimated by assuming the range of the data is four standard deviations. These data seem quite reasonable when compared against the sub-tasks involved.

Obtain Data and Plot Coordinates

"Obtain Data" and "Plot Coordinates" are treated as one task in the training documents. TDW #39 suggests four steps:

1. Extract latitude and longitude from a sensor message.

2. Select proper map.

3. Plot coordinates.

4. Convert plotted point to geographical location.

No estimate of completion times was obtained from the crews, so one will be synthesized. An estimate of the range will be made and then converted to mean and variance. These data are summarized in Table 3-6. The total task completion time is, therefore,

$$t_{PC} = t_1 + t_2 + t_3 + t_4$$

and

$$E(t_{PC}) = \sum_{i=1}^{4} E(t_i) = 20 \text{ sec.}$$

$$V(t_{PC}) = \sum_{i=1}^{4} V(t_i) = 5.75 \text{ sec.}$$

where $E(\cdot)$ refers to the expected value (or mean) and $V(\cdot)$ is the variance.

Therefore, the estimate for plot coordinates is

$$t_{PC} \approx N(20, 5.75) \quad .$$

TABLE 3-6. ESTIMATED COMPLETION TIMES FOR PLOT COORDINATES

SUBTASK	ESTIMATED RANGE	MEAN	VARIANCE
1) Extract Date	[3, 7]	5	1.0
2) Select Map	[2, 8]	5	2.25
3) Plot Coordinates	[4, 10]	7	2.25
4) Convert to Geog. Location	[2, 4]	3	0.25

Receive System Report

According to TDW #43, this task requires that the EVO receive the data verbally and in hard-copy form. These data consist of one of four classifications: false, under investigation, valid, all clear. It is assumed that this task is accomplished in 0.5 to 1.5 seconds, or,

$$t_{RSR} \approx N(1.0, .0625).$$

Brief

The final task is briefing the command post. The EVO must pass the sensor report, time of report, type of report, location, and the system report. Again we have no data concerning task completion times, and we assume

$$t_B \approx N(8,\ 4).$$

Estimate of Total Time Required

The cumulative completion time for the EVO in this phase of the problem is, therefore,

$$T = t_{BL} + t_{PC} + t_{RSR} + t_B$$

$$E(T) = 47$$

$$V(T) = 16$$

$$T \approx N(47,\ 16) \quad .$$

If this estimate is accurate, the 95 percent confidence interval on time required is approximately

$$39 < T < 55 \quad .$$

We conclude that the probability of one individual's completing these tasks within the time available for Time Epoch I is essentially zero, and that the EVO's activities constitute a critical path for Time Epoch I.

For purposes of illustration it is useful to consider one additional set of tasks in Time Epoch I, namely those performed by the CD when obtaining CINC assessment (Table 3-3). Again, a time budget is allocated in the scenario to request the assessment, receive the assessment, and tell the EVO to enter the assessment into the NCS. If only a few seconds are required for each step, the available time is sufficient. This, however, assumes that the CINC assessment is determined at the time the request is made. In other words, CINC must anticipate the requirement and have it available at the required time.

Similar examples can be found at several places throughout the system. These all show the importance of well trained and integrated crews. A new crew member or substitute might not be able to anticipate the needs of other crew members, and total performance would degrade.

3.4.4 Conclusions

The conclusions are of two classes, specific to the MWC/CP application exercise and methodological.

Even though a complete analysis of each task was not performed, it was demonstrated that sufficient time is not available for completion of all tasks as required by the formal system description. This may account for many of the reports of substantial differences in crew operating styles and substantial informal communication and informal organization.

The findings also emphasize the need for good training. Crew members must be aware of the requirements and expectations placed on other members of the team. This enables compensating behavior on the part of less loaded crew members to aid more highly loaded members even though such aiding may not be called for in the formal task descriptions.

In terms of methodology, several conclusions are important. First, the structural and descriptive data provided by IAT are quite complete and support a variety of analyses. By carefully analyzing the data flows and flow charts, it was possible to identify system performance characteristics and potential problems. This analysis can be qualitative or quantitative. Quantitative analysis is somewhat more speculative and requires more detail about processes such as that provided by the task description worksheets.

The NORAD example reinforces the need to have a number of analysis techniques rather than just one. An early IAT assumption was that queues would be sufficient for quantifying congestion, but that is not true as demonstrated by this example. In this system the process is more like a project management problem in that several activities are performed, some in parallel, some in sequence, in order to complete this overall task. Congestion occurs because of the precedence requirements placed on activities. If overall completion times are not satisfactory, the activities on the critical path must be examined. Improved time-lines might result from reallocation of resources to the activity, a redefinition of the procedures, or better work aids. But it is the critical path that deserves this attention.

Queuing theory, on the other hand, would be appropriate when congestion is due to operators performing relatively homogeneous tasks in a repetitive fashion. Further, queuing requires that work or tasks are somehow buffered in the system.

The general lesson to be learned is that one of the primary benefits of IAT's structured approach is a good, complete descriptive database. Given such data, an analyst can formulate many ways to answer questions, and it would be counterproductive and inefficient to constrain the set of tools at this (or, possibly, any) stage. It is also, perhaps, naive to assume that the process can be performed without a skilled analyst at our current state of knowledge. However, future systematic application of IAT, especially in a computer-assisted form, should result in comprehensive databases that will support the necessary methodology to make the skilled analyst less necessary in the future.

Finally, experience to date suggests that quantitative analysis is somewhat speculative because of imprecise and missing data. This suggests that valid quantitative analysis is probably restricted to (1) comparisons of alternative system implementations in which some base data can be used, or (2) sensitivity analyses. Both types of analysis are extremely useful and helpful in system design, so such applications are not severe restrictions on the use of IAT at present. However, it is anticipated that as IAT matures and a full set of frame types and their associated templates are developed, the problem of data voids will diminish through more complete data collection and the use of acceptable default values.

SECTION 4

AIR DEFENSE APPLICATION*

4.1 INTRODUCTION

In this section, a complete Petri net representation of a more complex C^3 system involved in an air defense mission is presented. According to the IAT methodology described in Volume I, a hierarchical Petri net representation with five levels of detail was developed. Each of the first four levels represents the entire air defense system. Level V represents those areas of the system which require more detail than could be accommodated in Level IV.

Levels I and II consist of a single diagram each and provide highly aggregated representations of the air defense system. Due to the increased detail in Levels III - V, we make no attempt to represent these levels on a single page. Thus, Level III consists of Diagrams Three and Four; Level IV consists of Diagrams Five through Fourteen; and Level V consists of Diagrams Fifteen through Twenty. Diagrams Twenty-one through Twenty-three are supplements that present additional detail that is appropriate to several different places in Level V. We partitioned Levels III - V into subsets of higher levels along the following lines: major air defense functions (i.e., detection, tracking, identification, weapons allocation, and engagement), and class of target (i.e., friendly or hostile). For ease of reference each diagram has a number indicating the level of detail it represents, as well as lateral pointers to indicate connections to diagrams on the same level.

Level I stresses the major concerns of the air defense mission, that is leakage of hostile aircraft and fratricide of friendly aircraft, at a very aggregated level. Levels II - V answer the "why" questions associated with leakage and fratricide, i.e., "why did this hostile leak?" or "why was this friendly aircraft prosecuted?" Levels II and III approach these issues in a fairly aggregate fashion; e.g., the hostile escaped because it was not detected, the friendly was prosecuted because it was incorrectly identified, and so on. Levels IV and V introduce a greater level of complexity to these questions and point specifically to system capabilities, such as load capacity and resource availability, as well as to the effect of enemy attempts to disrupt the command and control process through jamming and direct strikes on resources.

*This application was supported by BDM Corporation subcontract S562-0300512, under Defense Communications Agency Contract DCA100-85-C-0063.

In developing the Petri net representations which are contained in this section, we tried to strike a balance between a rigid hierarchy and one which provides enough flexibility to obtain useful measures. Likewise, we simplified our representations wherever possible, while trying to maintain the flexibility for extensions. Thus, at Level IV, we discuss only bombers and fighters; however, the Petri net representation is general enough to be applicable to cruise missiles and helicopters.

The remainder of this section consists of the diagrams which make up the Petri net representation for Levels I - V, plus the supplementary diagrams of the air defense mission. Each diagram is accompanied by a description of the flow of tokens through that section of the Petri net. The minimal independent set of measures associated with these diagrams is discussed in Section 5.

4.2 LEVEL I

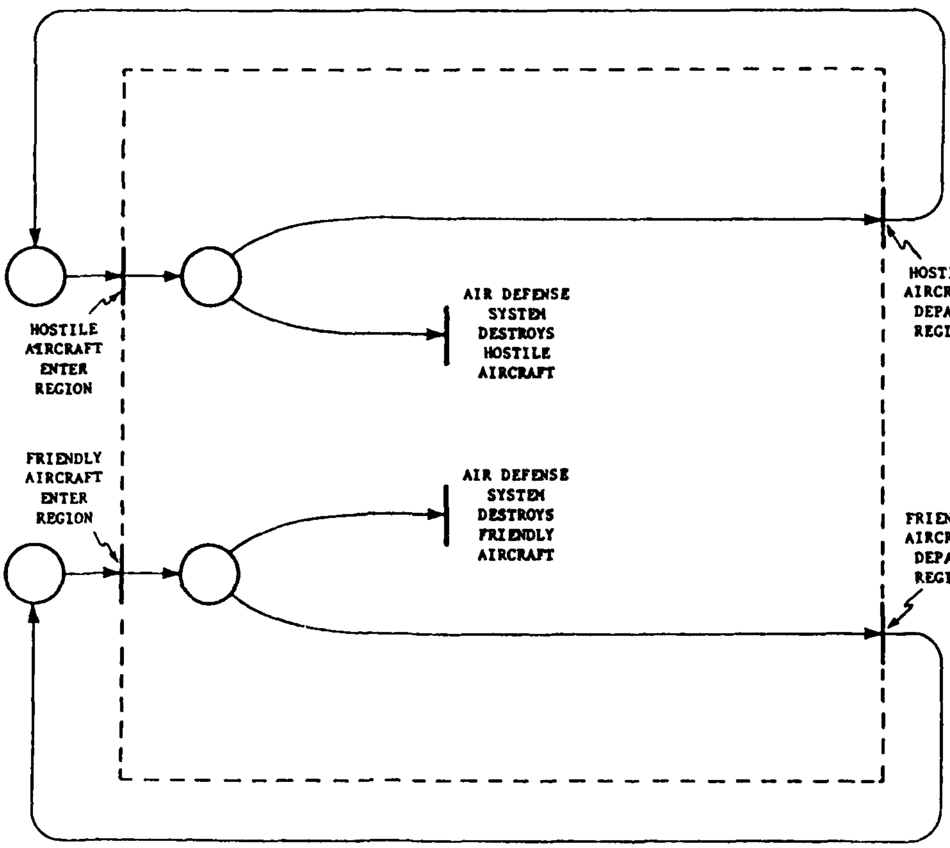
Level I stresses the two major concerns of the air defense system: leakage and fratricide. At this highly aggregated level, we focus on the destruction of hostile aircraft in the Air Defense Region (ADR) versus the leakage of hostile aircraft out of the ADR, and the safe passage of friendly aircraft through the ADR versus the fratricide or destruction of friendly aircraft. Here we are concerned solely with the aggregate rates, probabilities, and delays associated with leakage and fratricide. At lower levels, we break these down further (e.g., leakage prior to mission completion, leakage of damaged hostile aircraft, etc.).

The air defense mission is concerned with destroying enemy aerospace forces in a given region, and allowing friendly aerospace forces to operate safely in that region. Clearly then, an effective air defense system is one which reduces leakage and fratricide.

4.2.1 Diagram One

Diagram One represents the entire air defense system at a highly aggregated level. In Diagram One, hostile aircraft entering the ADR are either destroyed by the air defense system or they escape from the regions. Similarly, friendly aircraft entering the region are either destroyed by the air defense system or they exit from the region. (Note that friendly aircraft does not include air defense weapons such as fighter-interceptors or surveillance assets such as AWACS.)

The difference between the two paths through the ADR is that the numbers associated with destruction and escape/exit should be radically different for hostile and friendly aircraft. Specifically, an effective air defense system will show a larger proportion of the tokens representing hostile aircraft firing the "air defense system destroys hostile aircraft" transition than the "hostile aircraft escapes from ADR" transition, and a larger proportion of the tokens representing friendly aircraft firing the "friendly aircraft exits from the ADR" transition than the "air defense system destroys friendly



LEVEL I - DIAGRAM 1

R-3416

Figure 4-1. Level I - Diagram One

aircraft." In other words, an effective air defense system will have high hostile destruction and safe friendly passage rates (or, low leakage and fratricide rates).

4.3 LEVEL II

Level II introduces two functions of the air defense systems, detection and weapons allocation, as well as two groups of assets available to the air defense system, namely surveillance assets and air defense weapons. At Level II we are still focusing primarily on leakage and fratricide. At this level, leakage occurs at three points: the hostile target escapes before being detected, after detection and prior to prosecution, or in the course of being prosecuted. Fratricide occurs when a friendly aircraft is "successfully" prosecuted by the air defense system; i.e., the friendly gets in the "target stream" and does not exit from it before detection, before weapons allocation, and/or does not escape prosecution.

4.3.1 Diagram Two

Diagram Two is a refinement of Diagram One and shows in greater detail how the air defense system reacts to aircraft in the ADR. Targets (hostile and friendly) entering the region may be detected; if detected and identified, they may be assigned to weapons and prosecuted; and if prosecuted, they may be destroyed. Likewise, targets which have entered the ADR may leave the region without being detected; if detected, they may leave without being prosecuted; and, if subject to prosecution, they may still escape the region.

Diagram Two introduces two classes of assets available to the air defense system: surveillance assets and air defense weapons. The dotted lines connecting the population of surveillance assets to the "Detect Target" transitions indicate that surveillance assets (e.g., radars) do not operate on a one-to-one basis with targets that are detected; that is, these assets do not become unavailable as targets are detected. Some surveillance assets, however, must be available in order for detection to take place at all. Note that surveillance assets do become unavailable as they are destroyed by enemy action. In contrast to surveillance assets, air defense weapons do prosecute targets one at a time. Thus, while prosecuting an individual target, a weapon is not available to prosecute other targets (ignoring interrupts). Like surveillance assets, air defense weapons can be destroyed by enemy action apart from engagements.

The representation of a target engagement in Diagram Two is deliberately simplified. At this level, an engagement may result in two possible outcomes: the target may escape, in which case the air defense weapon is assumed destroyed; or, the target is destroyed, in which case the air defense weapon is shown as becoming available (after some period of time for refueling, etc.). Diagrams Nine through Fourteen at Level IV and Diagram Twenty at Level V give more detailed presentations of the possible outcomes of an engagement.

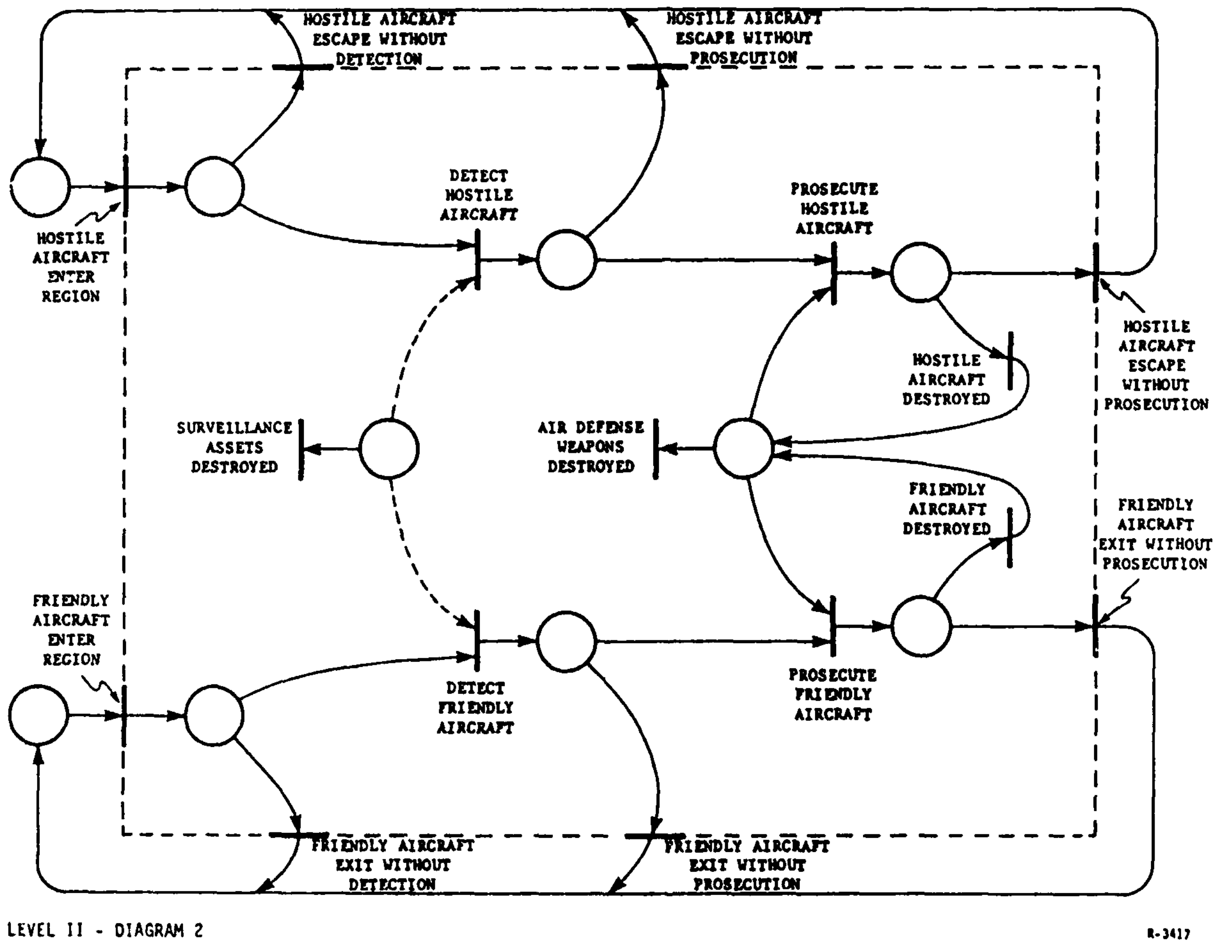


Figure 4-2. Level II - Diagram Two

4.4 LEVEL III

Level III introduces the tracking and identification functions of the air defense system. Given the increased detail, Level III and subsequent levels cannot be adequately presented on a single page. For Level III, we present the air defense system in two diagrams. Diagram Three presents the activities of the air defense system relative to hostile aircraft. Diagram Four presents the parallel development for friendly aircraft. Diagrams Three and Four are identical, except that the tokens in the network represent different groups of targets. When this situation occurs at subsequent levels, we will present only one diagram and discuss the parallel situations in the text. For continuity we maintain the distinction between hostile and friendly aircraft at Level III.

4.4.1 Diagram Three

Diagram Three refines the activities of the air defense system relative to hostile aircraft as presented in Diagram Two. In Diagram Three, hostile aircraft entering the ADR may be detected (if surveillance assets exist). If the hostile aircraft are detected, the air defense system will attempt both to identify and to track the aircraft. The activities of tracking and identification are also dependent on the existence (and nature) of the surveillance assets. If the hostile aircraft are both identified and tracked, weapons may be allocated to prosecute the aircraft. If weapons are allocated, they become unavailable for the duration of the engagement. In this simplified representation, either the aircraft escapes or it is destroyed; if it is destroyed, the air defense weapon becomes available to prosecute other aircraft. For greater detail of the engagement of hostile aircraft, see Diagrams Nine through Thirteen at Level IV and Diagram Twenty at Level V.

4.4.2 Diagram Four

Diagram Four refines the activities of the air defense system relative to friendly aircraft as presented in Diagram Two. Diagram Four is identical to Diagram Three, except that the tokens represent different populations of aircraft. In Diagram Four, friendly aircraft entering the ADR may be detected (if surveillance assets are available). If the friendly aircraft are detected, the air defense system will attempt both to identify and to track the aircraft. If the friendly aircraft are both identified and tracked, weapons may be allocated (if incorrectly identified as hostile or unknown) to prosecute the aircraft. If weapons are allocated, they become unavailable for the duration of the engagement. As in Diagram Three, this simplified representation shows that either the friendly aircraft escapes and exits the ADR or it is destroyed; if it is destroyed, the air defense weapon becomes available to prosecute other aircraft. For greater detail of the engagement of hostile aircraft, see Diagrams Nine, Twelve, and Fourteen at Level IV and Diagram Twenty at Level V.

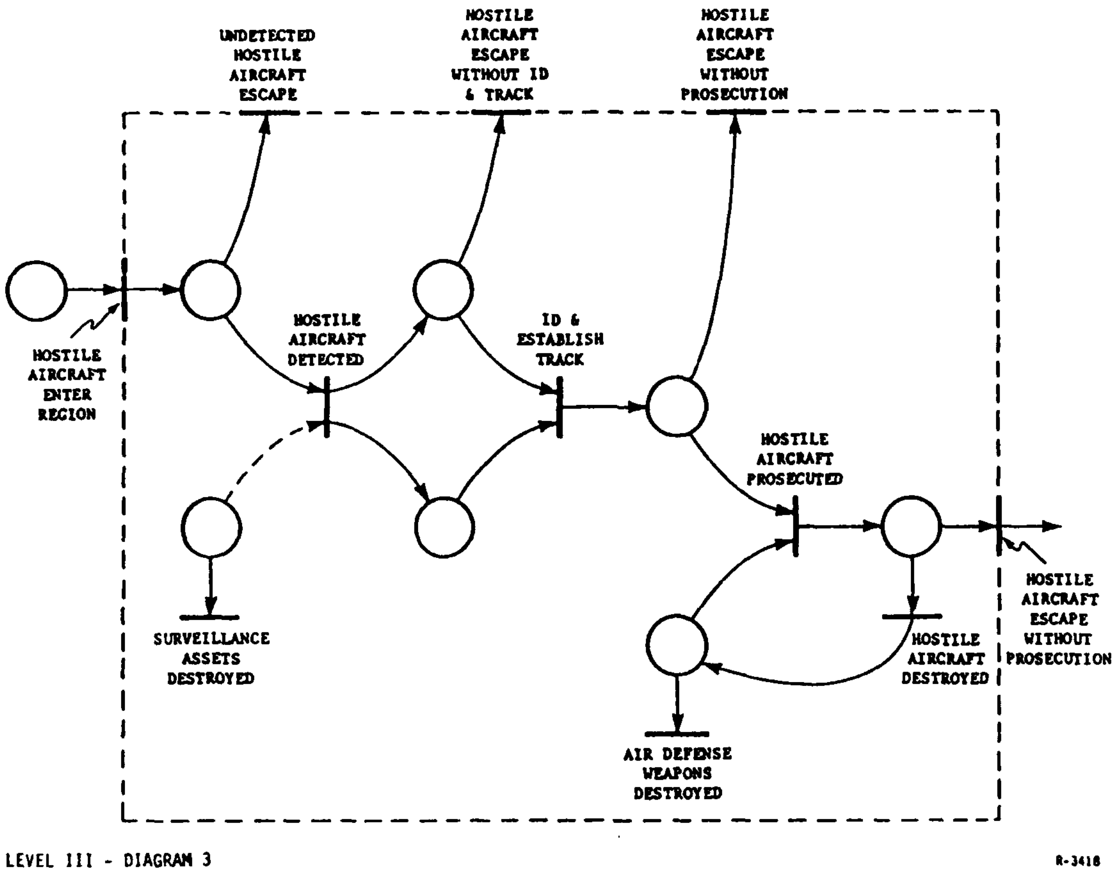


Figure 4-3. Level III - Diagram Three

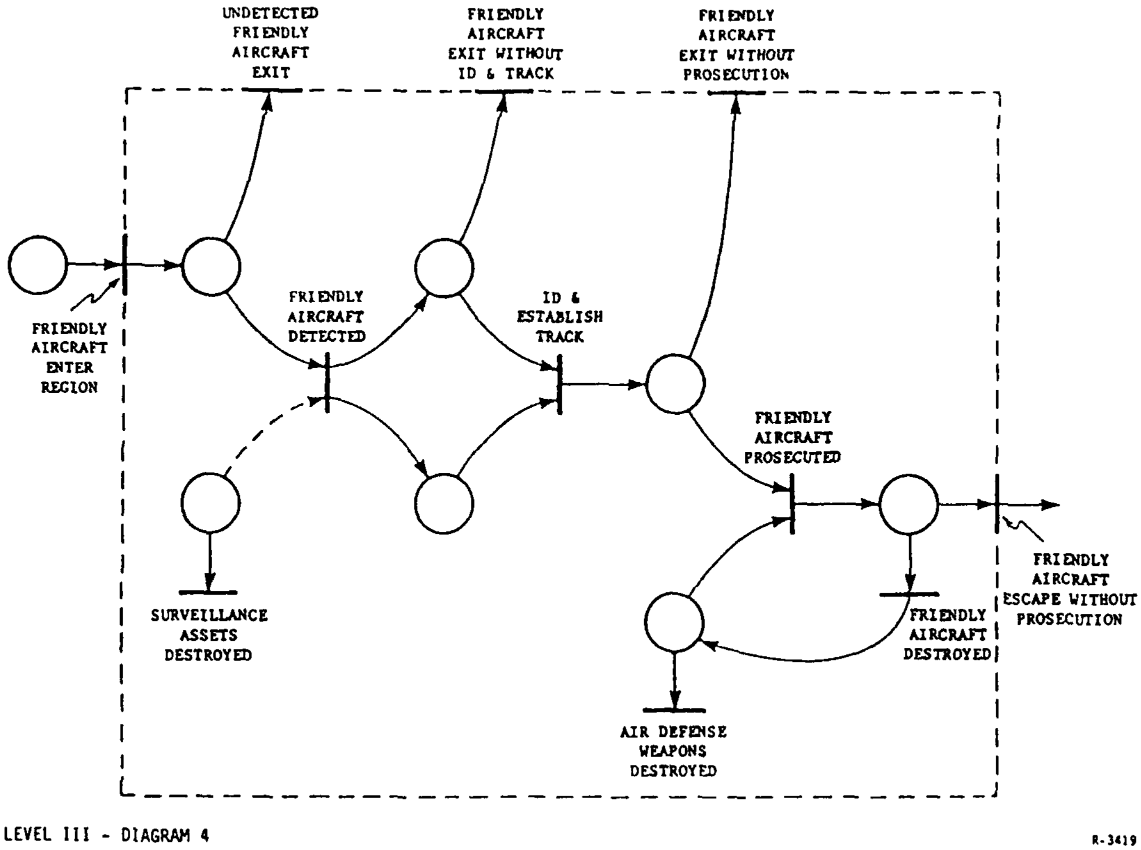


Figure 4-4. Level III - Diagram Four

Note that the populations of surveillance assets and air defense weapons in Diagrams Three and Four are the same populations. Thus, if an air defense weapon is allocated to a friendly aircraft, then it is not available to prosecute a hostile aircraft (and vice versa).

4.5 LEVEL IV

Level IV is presented in Diagrams Five through Fourteen. The flow of tokens through the diagrams at Level IV is shown in Fig. 4-5.

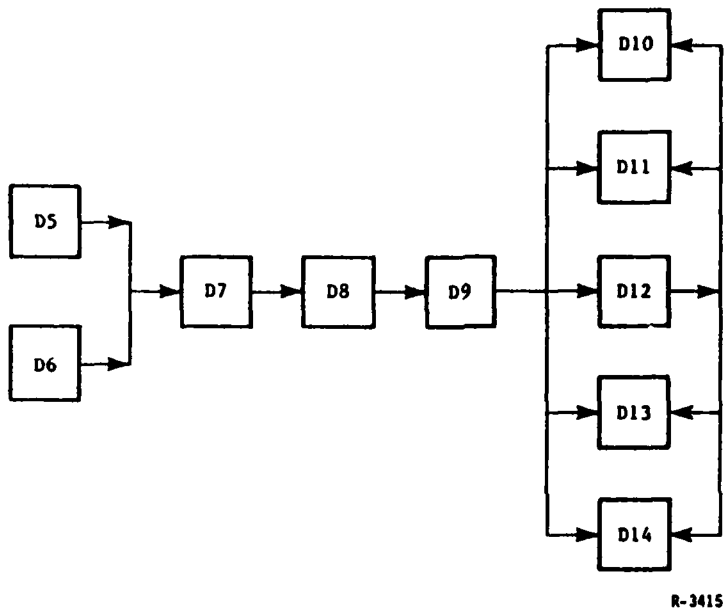


Figure 4-5. Diagrams in Level IV

Level IV introduces several new concepts. First, a distinction is drawn between post-mission and pre-mission hostile aircraft. Post-mission hostiles are those hostiles which have completed their missions and are on their way out of the ADR. Pre-mission hostiles are those hostiles which are en route to their missions. A successful air defense system will decrease the number of post-mission hostiles by detecting, tracking, identifying and prosecuting hostile aircraft before they complete their missions. Obviously, in a heavy load situation, some trade-offs will occur based on what the perceived missions of incoming hostiles are, i.e., the air defense system will want to protect its high value targets.

Second, Level IV introduces spoofing, or the generation of false targets. Spoofing is important because it places a greater load on the air defense system, taking up surveillance, communications, and data processing assets as well as critical air defense weapons, and disrupts the command and control process.

Communications and data processing assets are also introduced at Level IV. Communications assets are represented as circuits which are taken up as messages are sent and as enemy jamming is introduced. Circuits are freed up as messages are completed, jamming is overcome, etc. For more detail of this process, see supplementary Diagram Twenty-one. Data processing is represented in terms of capacity, that is, as more data processing is required, the capacity is reduced. The presence of limited communications assets and data processing capacity introduces the notion that the air defense system can only handle a limited load, which, when exceeded, results in the degradation of the functioning of the air defense system. (Note, we explicitly represent data processing capacity in Diagrams Six and Seven. For simplicity, we omit explicit reference to data processing in Diagrams Eight through Fourteen).

At Level IV, the identification process is broken down into two steps: identification by "nationality" friend or foe (IFF), and identification by type (as bomber or fighter). With the differentiation between bombers and fighters, we introduce the notion of selective targeting in the allocation process. This provides the flexibility to model a variety of strategies regarding targeting. Finally, Level IV provides a detailed representation of the engagement process for a wide range of targets (post-mission hostiles, pre-mission hostiles, false targets, and friendlies).

4.5.1 Diagram Five

Diagram Five presents the activities of the air defense system relative to the detection of hostile aircraft. It shows that hostiles entering the ADR may be detected (if surveillance assets are available). If detected before their missions are complete, they become pre-mission hostiles; if detected after completing their missions, they become post-mission hostiles.

Diagram Five presents three new concepts in the air defense system: spoofing, communications, and data processing. Spoofing refers to the activity by which hostile forces introduce false targets into the air defense system. Diagram Fifteen at Level V presents spoofing in greater detail. Communications assets, represented here as circuits, are a limited resource needed for each transition through the system. We show communications assets being freed up as messages are completed, jamming is overcome, etc. Supplementary Diagram Twenty-one shows this activity in greater detail.

Data processing is also a limited resource in terms of capacity. This limited capacity may result in targets being lost from the system even though surveillance and communications assets are available. If surveillance and communications assets are available, and if database capacity is available, both hostile aircraft and false targets will be entered into the database until the capacity is exceeded. Notice that data processing capacity becomes available as targets leave the ADR or leave the system (because of lost or dropped tracks), or are destroyed.

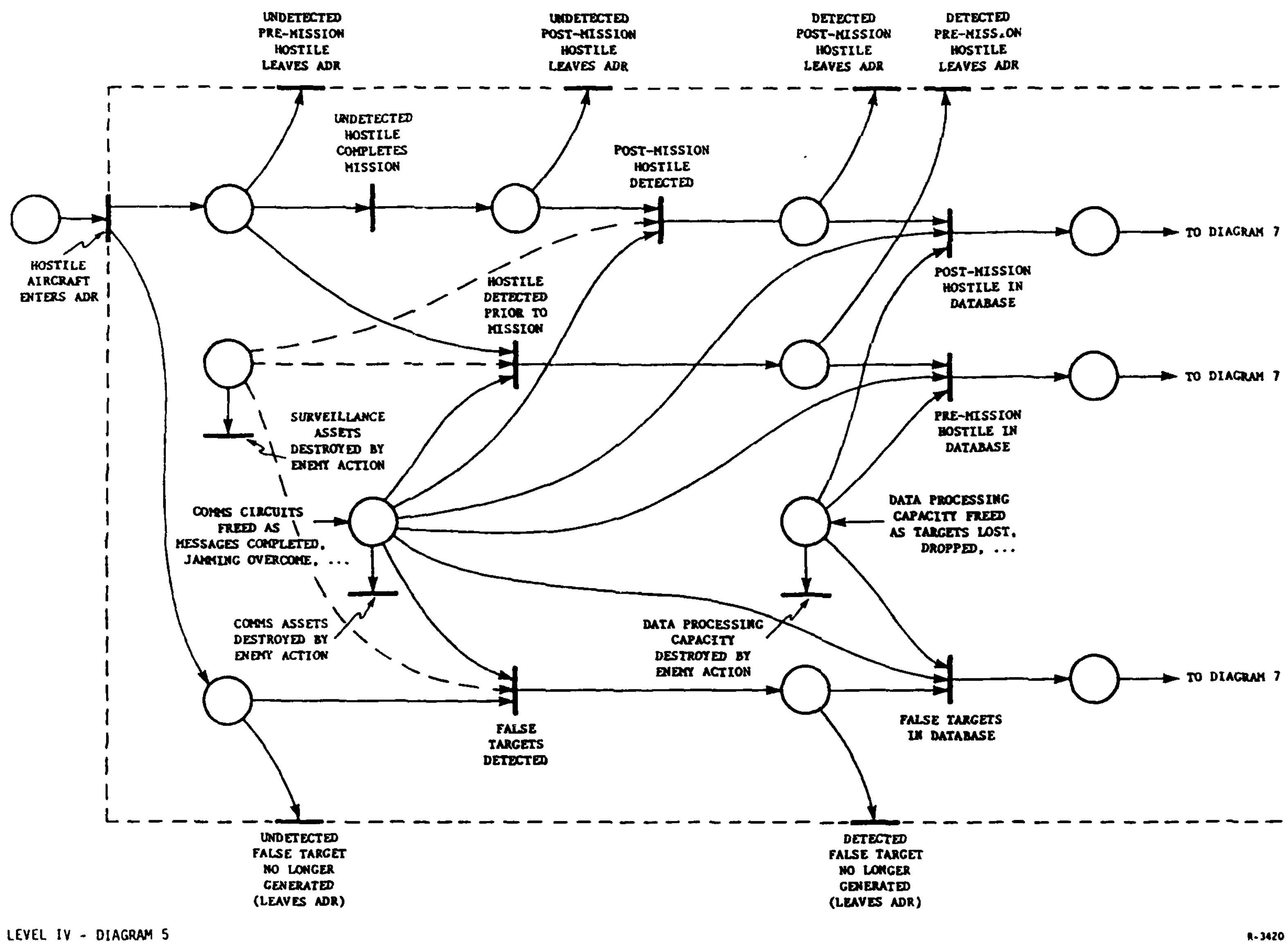


Figure 4-6. Level IV - Diagram Five

4.5.2 Diagram Six

Diagram Six shows the activities of the air defense system detecting friendly aircraft. In Diagram Six, friendly aircraft entering the region may be detected if surveillance assets are available, or they may exit without detection; if detected and data processing capacity is available, they may be entered into the database, or they may exit without being entered into the database. As in Diagram Five, communications assets must be available in order to note a detection and to enter it into the database.

4.5.3 Diagram Seven

Diagram Seven presents more details of the identification process. In this representation, a target is first identified by nationality (Friend or Foe). Diagram Seven represents four situations: the identification of post-mission hostile aircraft, the identification of pre-mission hostile aircraft, the identification of false targets, and the identification of friendly aircraft. Thus, there are four sets of tokens which can flow through the Petri net representation in Diagram Seven.

Given that a target is identified, it may be identified as either hostile, false, or friendly. If a target is not identified, it is classified as unknown. The likelihood of these particular identifications will depend on the type of target being identified as well as the surveillance assets available for identification.

A target may "Leave the System" before it is identified, either by physically leaving the region or because the system loses the target track. Also, if a target is identified as friendly or false, it eventually leaves the system, unless it is re-identified.

As before, the dotted line means that the electronic assets are necessary for those identifications to occur, but they do not become unavailable as identifications occur.

For a more detailed presentation of identification by nationality, see Diagram Seventeen at Level V.

4.5.4 Diagram Eight

Diagram Eight is similar to Diagram Seven and represents the common ways a target identified as unknown or hostile can be further identified according to type as a bomber or a fighter.

The attempt to identify the target by type may conclude that the target is a false target or that it is in fact friendly; otherwise it will be identified as an (unknown/hostile) bomber or (unknown/hostile) fighter. (These classifications are illustrative; others, e.g., cruise missiles, may be introduced as needed). This representation assumes that a target that cannot be identified by type will be classified as a bomber.

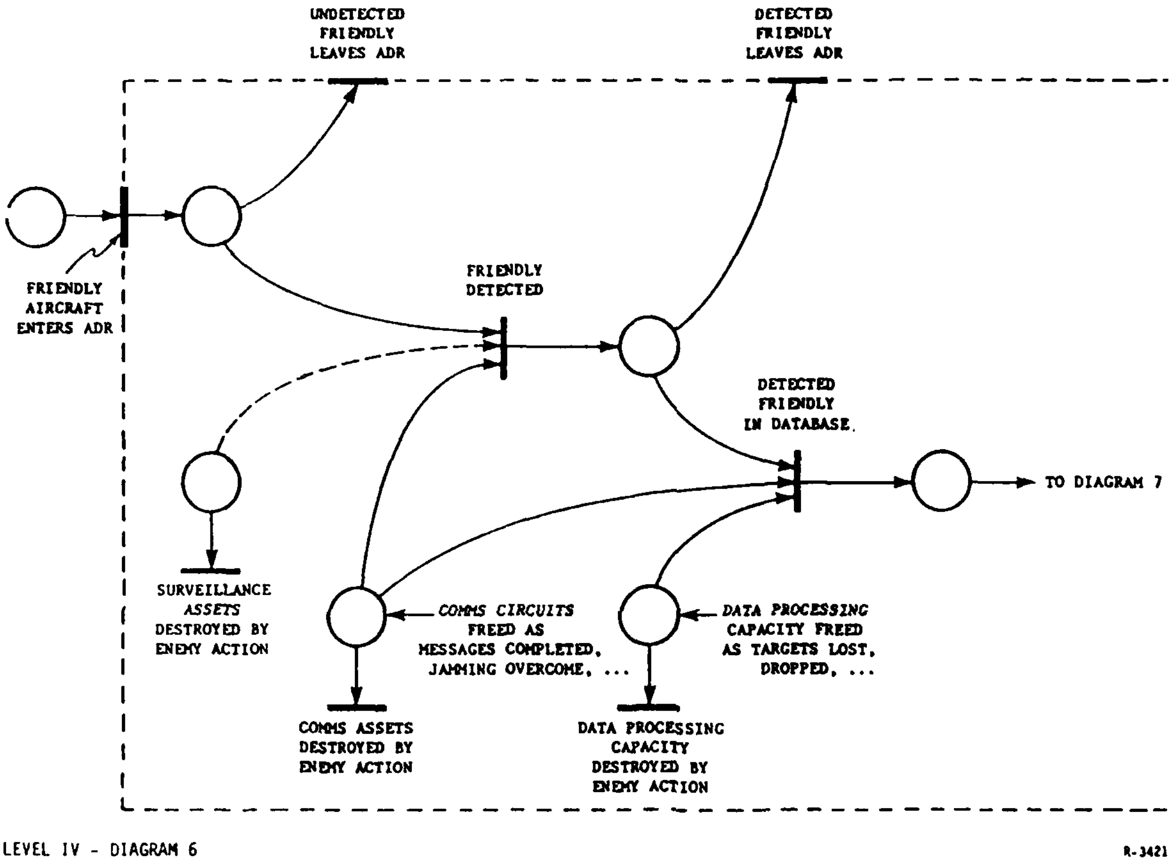


Figure 4-7. Level IV - Diagram Six

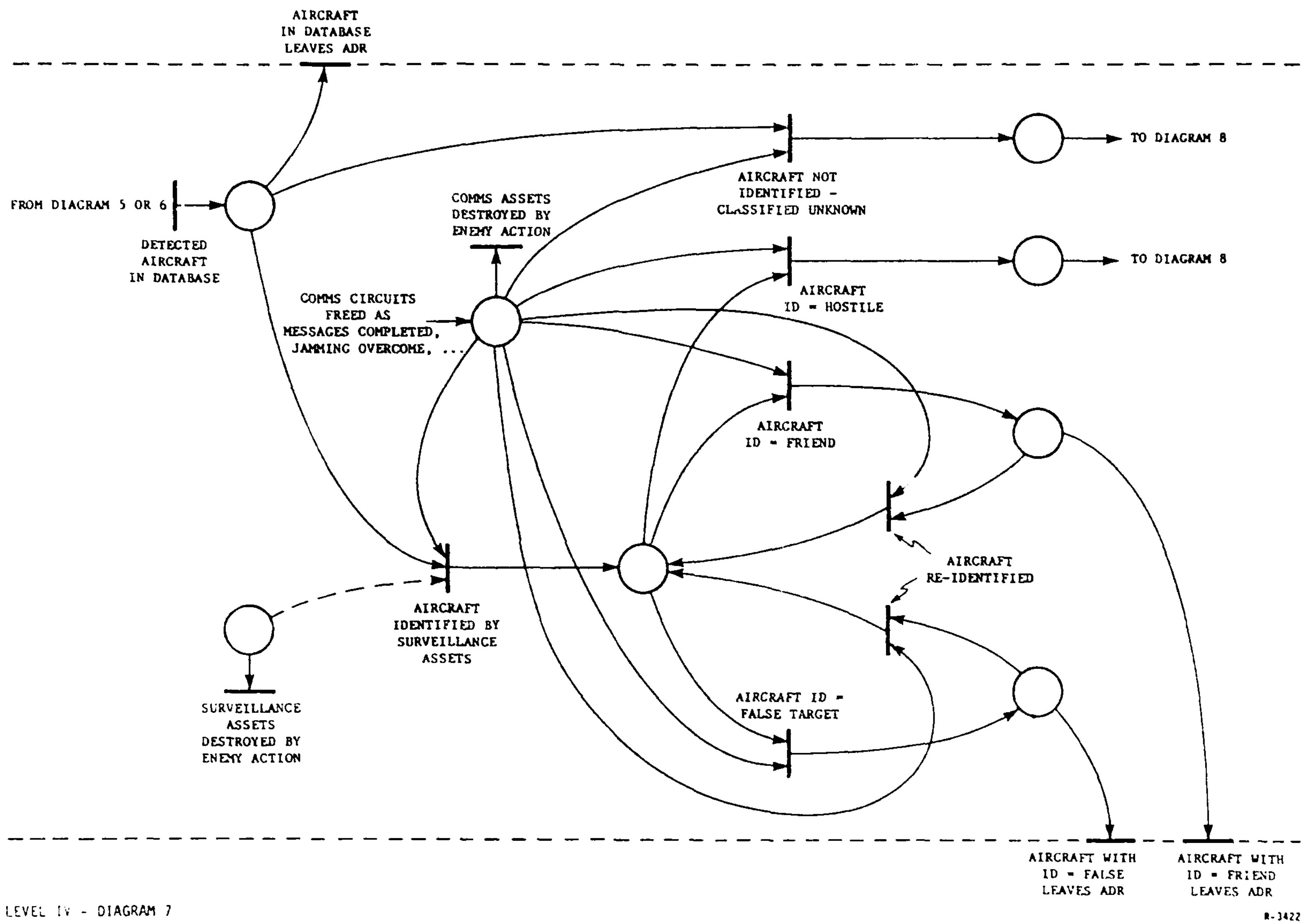


Figure 4-8. Level IV - Diagram Seven

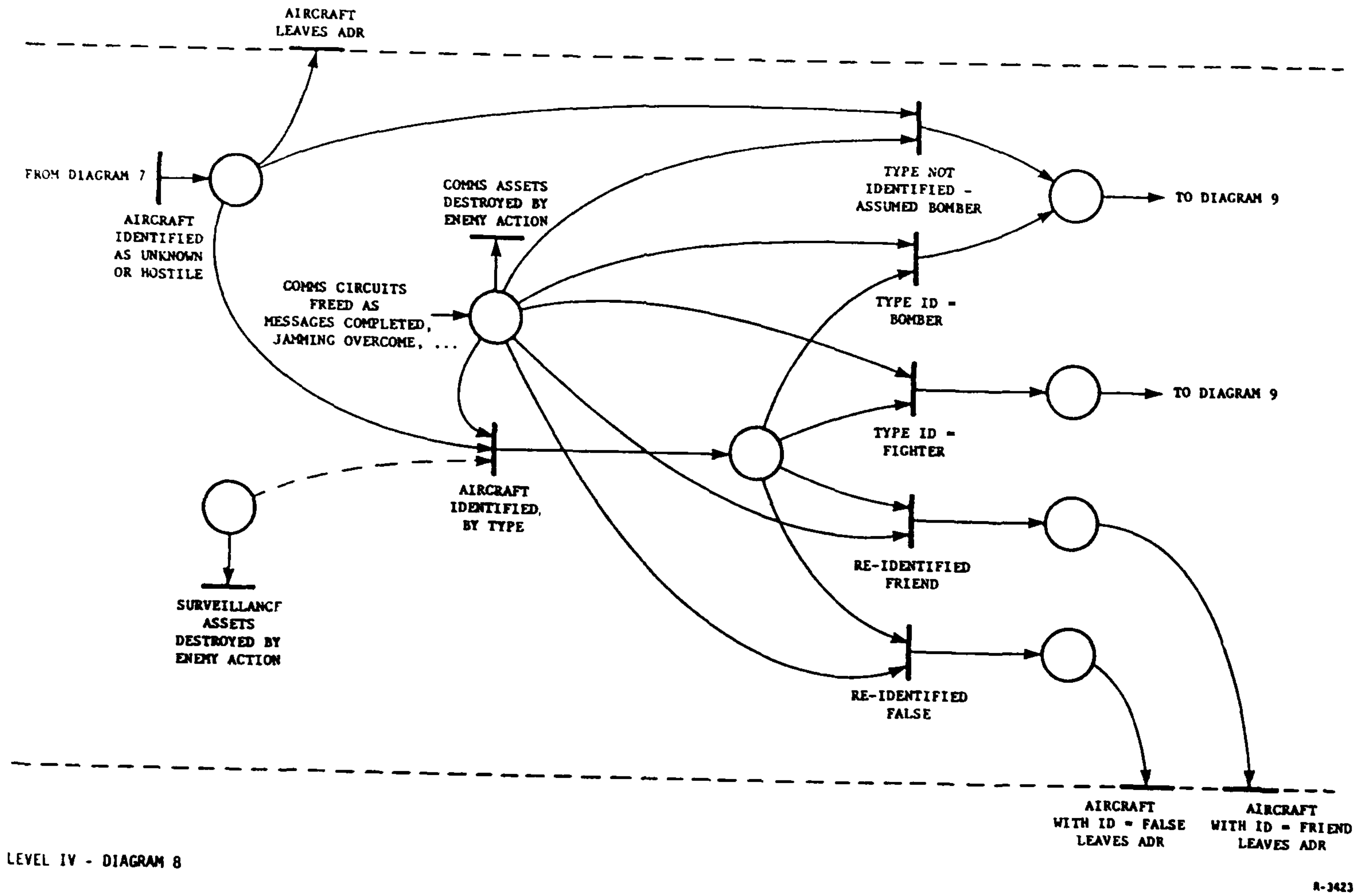


Figure 4-9. Level IV - Diagram Eight

Diagram Eight represents eight situations of identifying aircraft by type. The targets being identified are: post-mission hostile aircraft identified as unknown, pre-mission hostile aircraft identified as unknown, false targets identified as unknown, friendly aircraft identified as unknown, post-mission hostile aircraft identified as hostile, pre-mission hostile aircraft identified as hostile, false targets identified as hostile, and friendly aircraft identified as hostile.

As before, the dotted line means that the electronic assets are necessary for those identifications to occur, but they do not become unavailable as identifications occur.

4.5.5 Diagram Nine

Diagram Nine presents the weapons allocation process. If both bomber targets and fighter targets are available, then the air defense system must have a policy for allocating its assets between these two groups.

All targets classified as bombers flow through the upper path on the diagram. There are eight groups: post-mission hostile aircraft identified as unknown bombers, pre-mission hostile aircraft identified as unknown bombers, false targets identified as unknown bombers, friendly aircraft identified as unknown bombers, post-mission hostile aircraft identified as hostile bombers, pre-mission hostile aircraft identified as hostile bombers, false targets identified as hostile bombers, and friendly aircraft identified as hostile bombers.

Similarly, all targets classified as fighters flow through the lower path on the diagram. There are eight groups: post-mission hostile aircraft identified as unknown fighters, pre-mission hostile aircraft identified as unknown fighters, false targets identified as unknown fighters, friendly aircraft identified as unknown fighters, post-mission hostile aircraft identified as hostile fighters, pre-mission hostile aircraft identified as hostile fighters, false targets identified as hostile fighters, and friendly aircraft identified as hostile fighters.

Whatever the policy about allocating resources between fighters and bombers, allocations among pre- (and possibly post-) mission hostile bombers, friendly aircraft identified as hostile bombers, and false targets identified as hostile bombers will be entirely random, since to the air defense system they represent one population, not three (the same randomness applies for allocations among all the targets the system identifies as hostile fighters).

Note that the weapon-target pairings output from Diagram Nine go to one of five diagrams: to Diagram Ten for post-mission hostiles identified as hostile bombers and fighters; to Diagram Eleven for pre-mission hostiles identified as hostile bombers and fighters; to Diagram Twelve for all targets classified as unknown bombers and fighters; to Diagram Thirteen for false targets identified as hostile bombers and fighters; or, to Diagram Fourteen for friendly aircraft identified as hostile bombers and fighters.

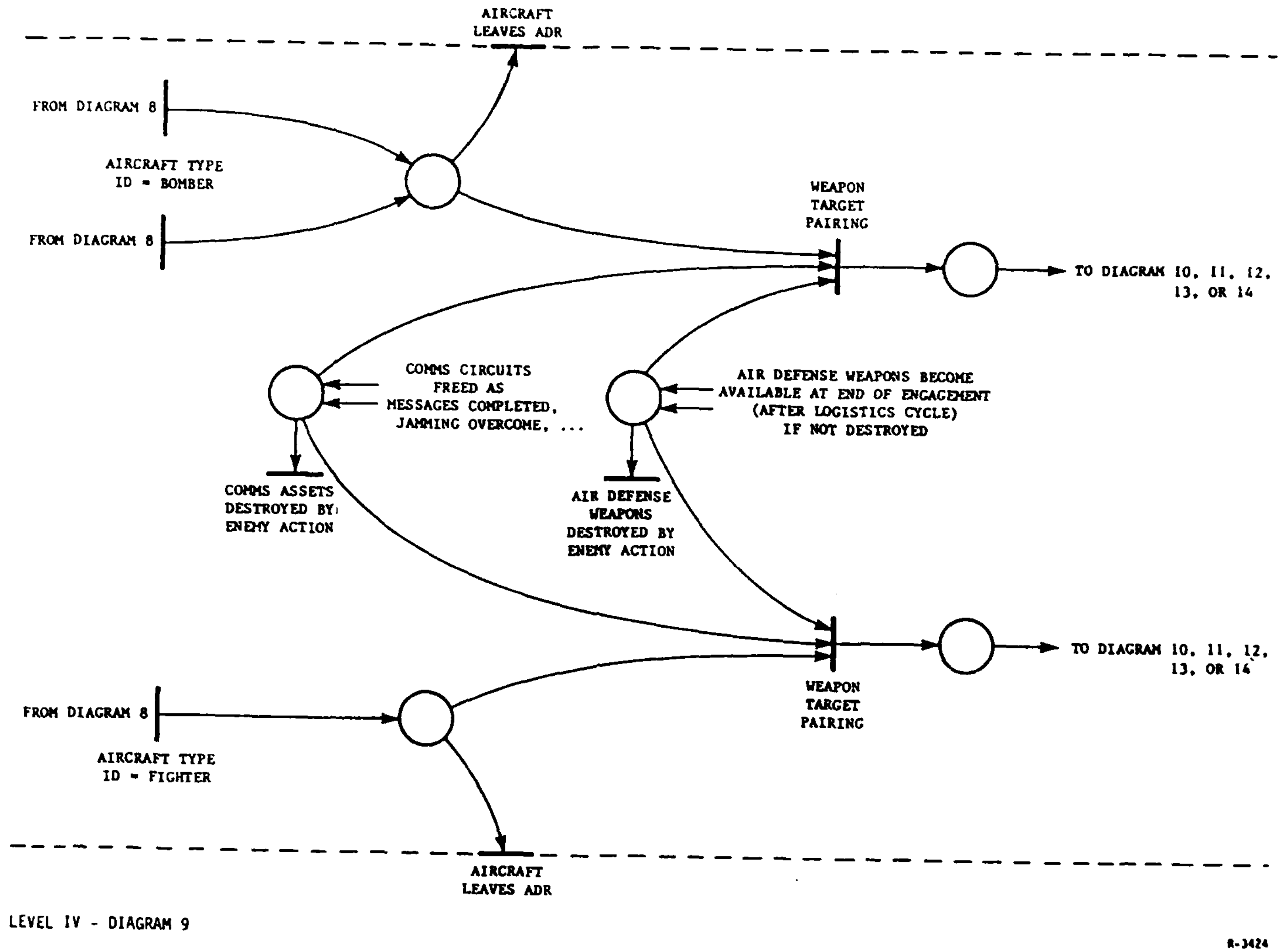


Figure 4-10. Level IV - Diagram Nine

4.5.6 Diagram Ten

Diagram Ten represents the air defense system's engagement of post-mission hostile aircraft that have been identified as hostile by the air defense system. (The engagement of post-mission hostile aircraft which have been identified as unknown is shown in Diagram Twelve). Diagram Ten represents two classes of post-mission hostile aircraft: bombers and fighters. These two populations, post-mission hostile bombers and post-mission hostile fighters, come from three transitions, thus representing more than one possible path through the air defense system.

Diagram Ten may represent: the first (or subsequent) engagement of a post-mission hostile aircraft which was initially identified as a hostile bomber or fighter (from Diagram Nine); the engagement of a post-mission hostile aircraft which escaped an engagement prior to completing its mission (from Diagram Eleven); or, the engagement of a post-mission hostile aircraft which was initially identified as an unknown, paired with an air defense weapon, and then identified as hostile (from Diagram Twelve).

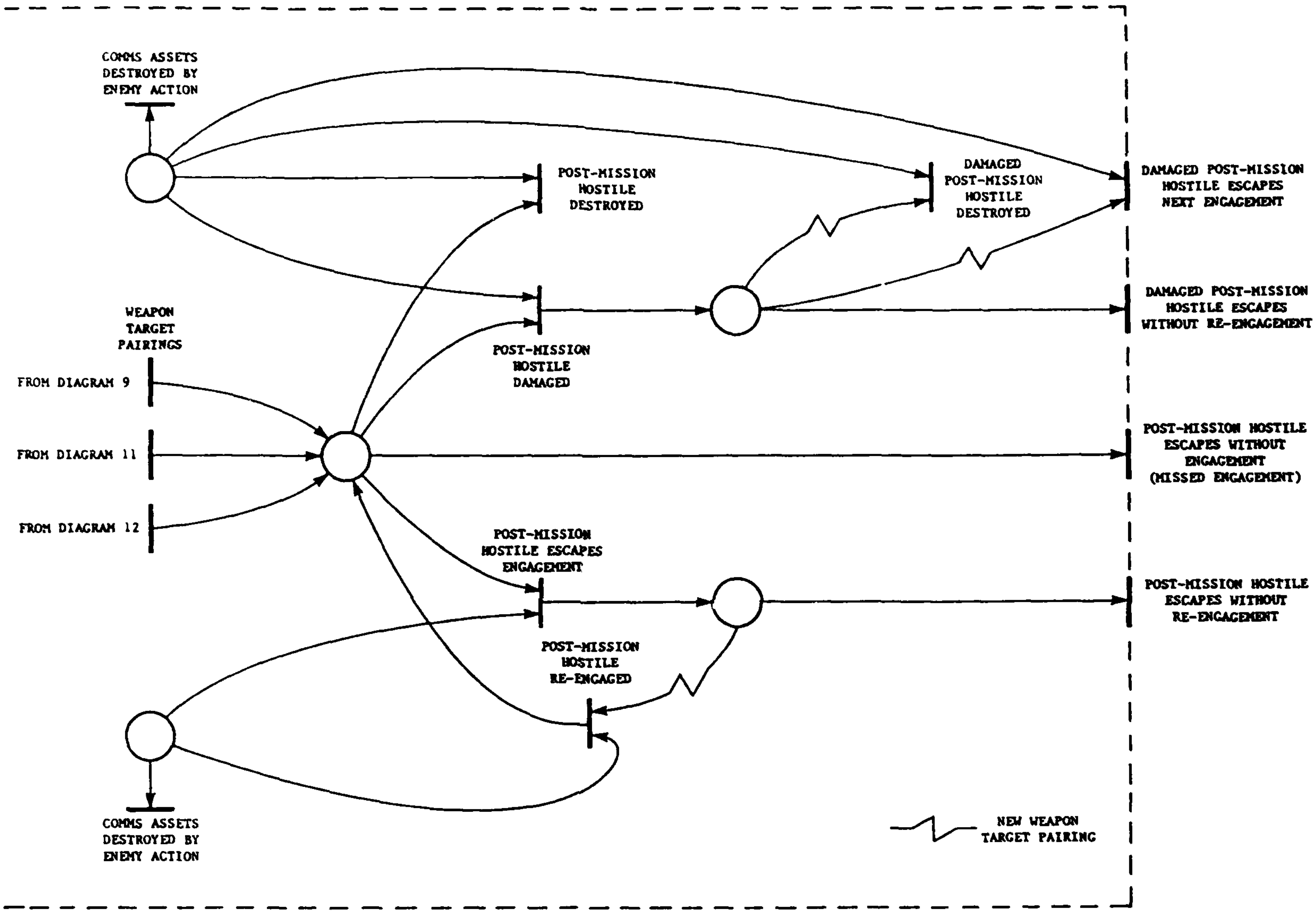
Depending on the strategy selected, the engagement of post-mission hostiles may or may not take place. For instance, if the air defense system stresses an area defense, it will allocate weapons to aircraft ingressing and egressing equally; if it stresses point defense, then aircraft on the way to their target will be engaged in preference to aircraft exiting.

4.5.7 Diagram Eleven

Diagram Eleven represents the air defense system's engagement of pre-mission hostile aircraft that have been identified as hostile bombers and fighters by the air defense system. (The engagement of pre-mission hostile aircraft which have been identified as unknown is shown in Diagram Twelve). Diagram Eleven represents two classes of pre-mission hostile aircraft: bombers and fighters. These two populations, pre-mission hostile bombers and pre-mission hostile fighters, come from two transitions, thus representing more than one possible path through the ADR.

Diagram Eleven may represent the first (or subsequent) engagement of a pre-mission hostile aircraft which has been identified as a hostile bomber or fighter (from Diagram Nine); or, a pre-mission hostile aircraft which was initially identified as unknown, paired with an air defense weapon, and later identified as hostile (from Diagram Twelve).

Diagram Eleven shows a number of outcomes for the engagement of a pre-mission hostile aircraft. A pre-mission hostile aircraft, which has been identified as a hostile bomber or fighter and paired with an air defense weapon, may: be engaged and destroyed; be damaged in an engagement and subsequently re-engaged and destroyed, escape re-engagement, or escape from the ADR without being re-engaged; escape from the ADR due to a missed engagement; escape an engagement and subsequently escape from the ADR without being re-engaged, complete its mission and escape from the ADR without being



LEVEL IV - DIAGRAM 10

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Figure 4-11. Level IV - Diagram Ten

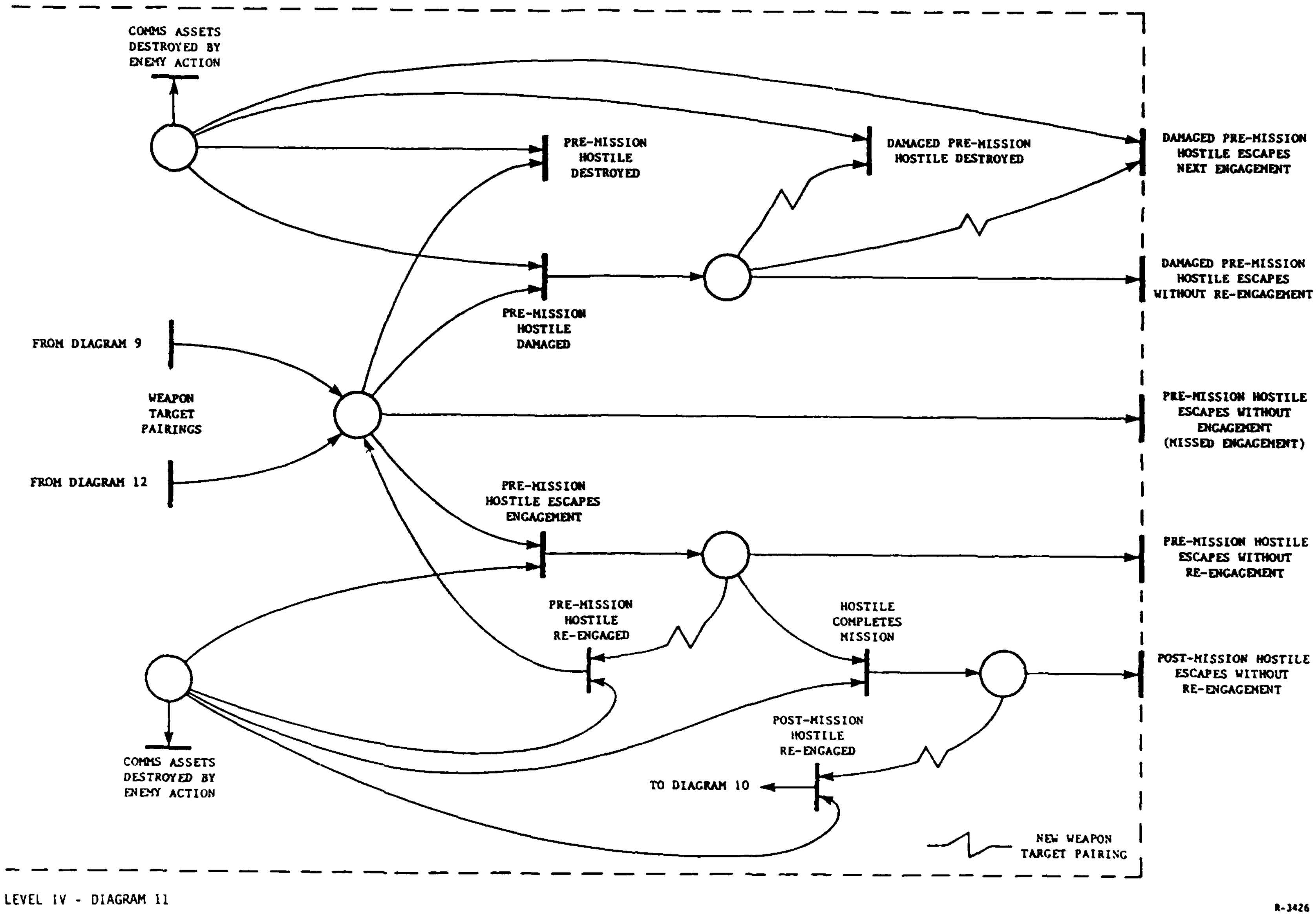


Figure 4-12. Level IV - Diagram Eleven

re-engaged, complete its mission and be paired with an air defense weapon for re-engagement, or be re-engaged prior to completing its mission. A pre-mission hostile aircraft which escapes an engagement and completes its mission becomes a post-mission hostile. The subsequent prosecution of this post-mission hostile aircraft, if it occurs, is depicted in Diagram Ten.

4.5.8 Diagram Twelve

Diagram Twelve represents the outcomes for weapon target pairings in which the nationality of the target is unknown. Diagram Twelve represents eight types of targets: post-mission hostile aircraft identified as unknown bombers, pre-mission hostile aircraft identified as unknown bombers, false targets identified as unknown bombers, friendly aircraft identified as unknown bombers, post-mission hostile aircraft identified as unknown fighters, pre-mission hostile aircraft identified as unknown fighters, false targets identified as unknown fighters, friendly aircraft identified as unknown fighters.

There are four possible outcomes: the unknown aircraft may be identified as friendly and be allowed to safely exit; it may be identified as hostile and prosecuted; it may be identified as a false target and dropped from the database; or, it may leave the region without being further identified. The prosecution of any target which is identified as hostile is depicted in one of four diagrams: Diagram Ten if the target is a post-mission hostile; Diagram Eleven if the target is a pre-mission hostile; Diagram Thirteen if it is a false target; or, Diagram Fourteen if it is a friendly.

The probability that an unknown bomber or fighter will be identified as friendly, hostile, or false, or leave without being further identified, depends on what type of target it is and on the rules of engagement. For instance, if the rules of engagement state that an unknown target must be visually identified before it can be prosecuted, the probability that an unknown hostile will be identified as hostile is fairly high; likewise, the probability that an unknown friendly will be identified as friendly is high under these rules of engagement. If, however, the rules of engagement state that after some specified amount of time an unknown aircraft will be assumed to be hostile and can then be prosecuted, the probability that an unknown target will be identified as hostile will be close to 1.0 for both hostile aircraft and friendly aircraft. Thus, Diagram Twelve can be used to represent a variety of scenarios.

4.5.9 Diagram Thirteen

Diagram Thirteen represents the air defense system's engagement of false targets that have been identified as hostile bombers and fighters by the air defense system. These two populations, false targets identified as hostile bombers and false targets identified as hostile fighters, come from two transitions. Diagram Thirteen may represent the first (or subsequent) "engagement" of false targets which have been identified as hostile bombers and fighters (from Diagram Nine); or, false targets which were initially

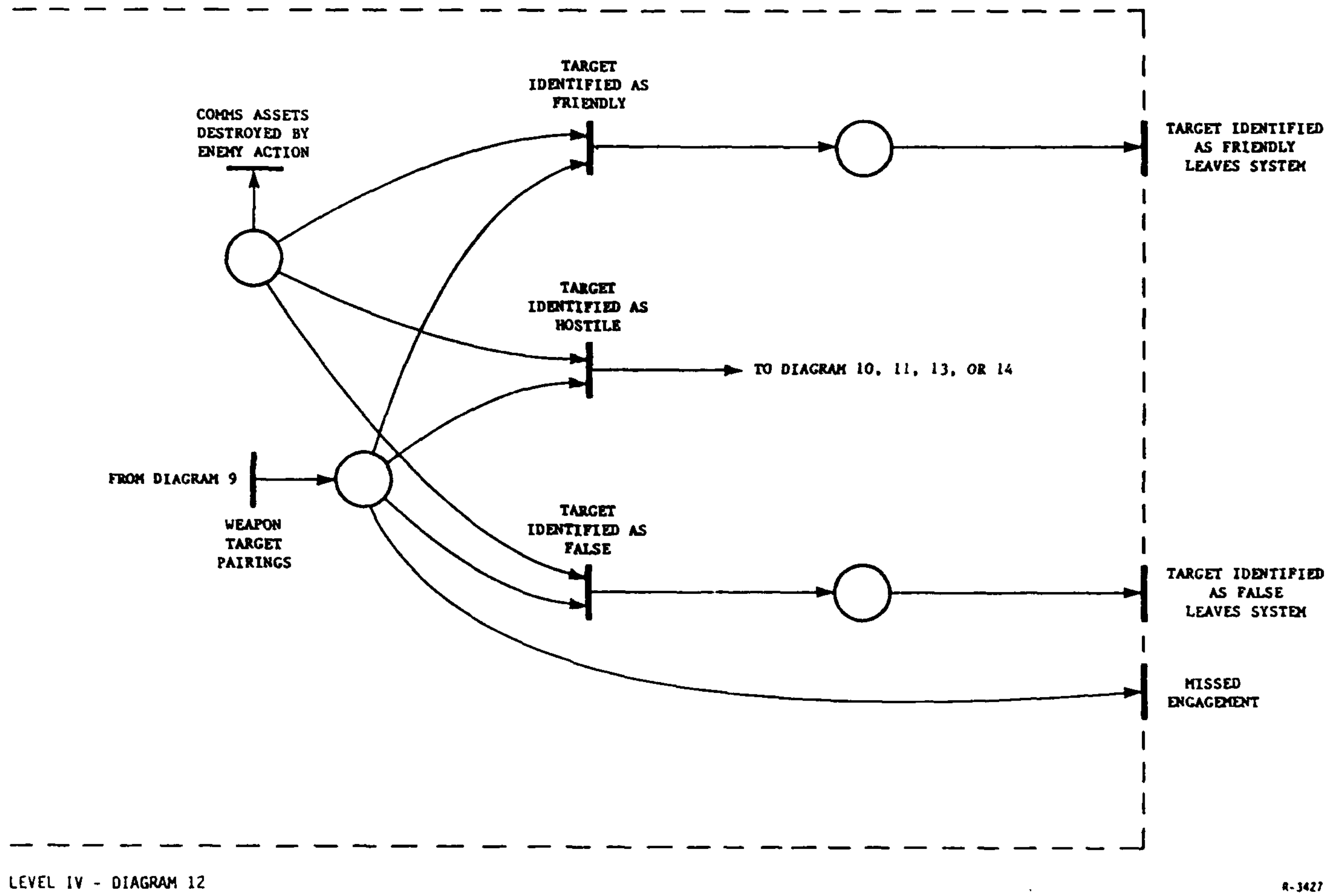


Figure 4-13. Level IV - Diagram Twelve

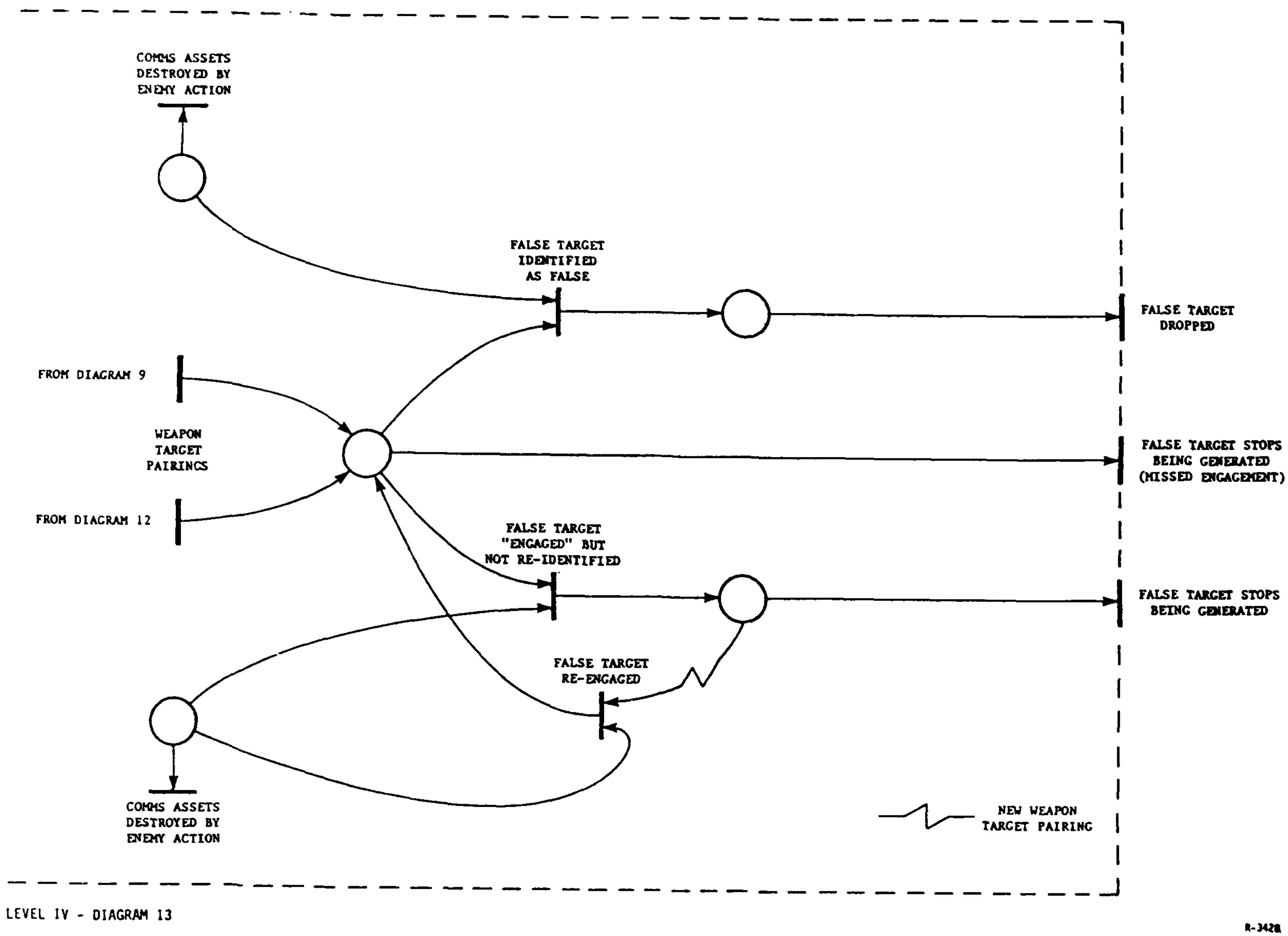


Figure 4-14. Level IV - Diagram Thirteen

identified as unknown, paired with air defense weapons, and later identified as hostile (from Diagram Twelve).

Diagram Thirteen shows four possible outcomes for the engagement of a false target identified as a hostile bomber or fighter: it may be identified as a false target and dropped from the database; it may stop being generated before it can be re-identified; or it may "escape an engagement" (that is, it may continue to be generated and keep an air defense weapon busy), and subsequently stop being generated or be paired with an air defense weapon for re-engagement (thus, potentially wasting SAMs or fighter-interceptor time).

4.5.10 Diagram Fourteen

Diagram Fourteen represents the air defense system's engagement of friendly aircraft that have been identified as hostile bombers and fighters by the air defense system. These two populations, friendly aircraft identified as hostile bombers and friendly aircraft identified as hostile fighters, come from two transitions. Diagram Fourteen may represent the first (or subsequent) engagement of friendly aircraft which have been identified as hostile bombers and fighters (from Diagram Nine); or, friendly aircraft which were initially identified as unknown, paired with air defense weapons, and later identified as hostile (from Diagram Twelve).

The engagement of a friendly aircraft by the air defense system can result in a number of possible outcomes as shown in Diagram Fourteen. A friendly aircraft, which has been paired with an air defense weapon for engagement may: be damaged in an engagement and subsequently re-engaged and destroyed, escape re-engagement and exit from the ADR, exit from the ADR without being re-engaged, or be identified as friendly and allowed to exit from the ADR; engaged and destroyed; exit from the ADR due to a missed engagement; be identified as friendly and allowed to exit from the ADR; or, escape an engagement and subsequently escape re-engagement and exit from the ADR, exit from the ADR without being re-engaged, be identified as friendly and allowed to exit from the ADR, or be re-engaged.

4.6 LEVEL V

The diagrams in Level V do not themselves comprise a complete picture of the air defense system (as do Levels I through IV). Rather, each diagram at this level presents an expansion of some part of a diagram in Level IV. The relationship between the diagrams is shown in Fig. 4-16.

4.6.1 Diagram Fifteen

Diagram Fifteen gives more detail on the generation of false targets (spoofing). It shows that, as hostile aircraft (shaded in the diagram) enter the region they will employ EW assets (on board or escort) which will generate some number of false targets. In addition, ground-based enemy EW assets from

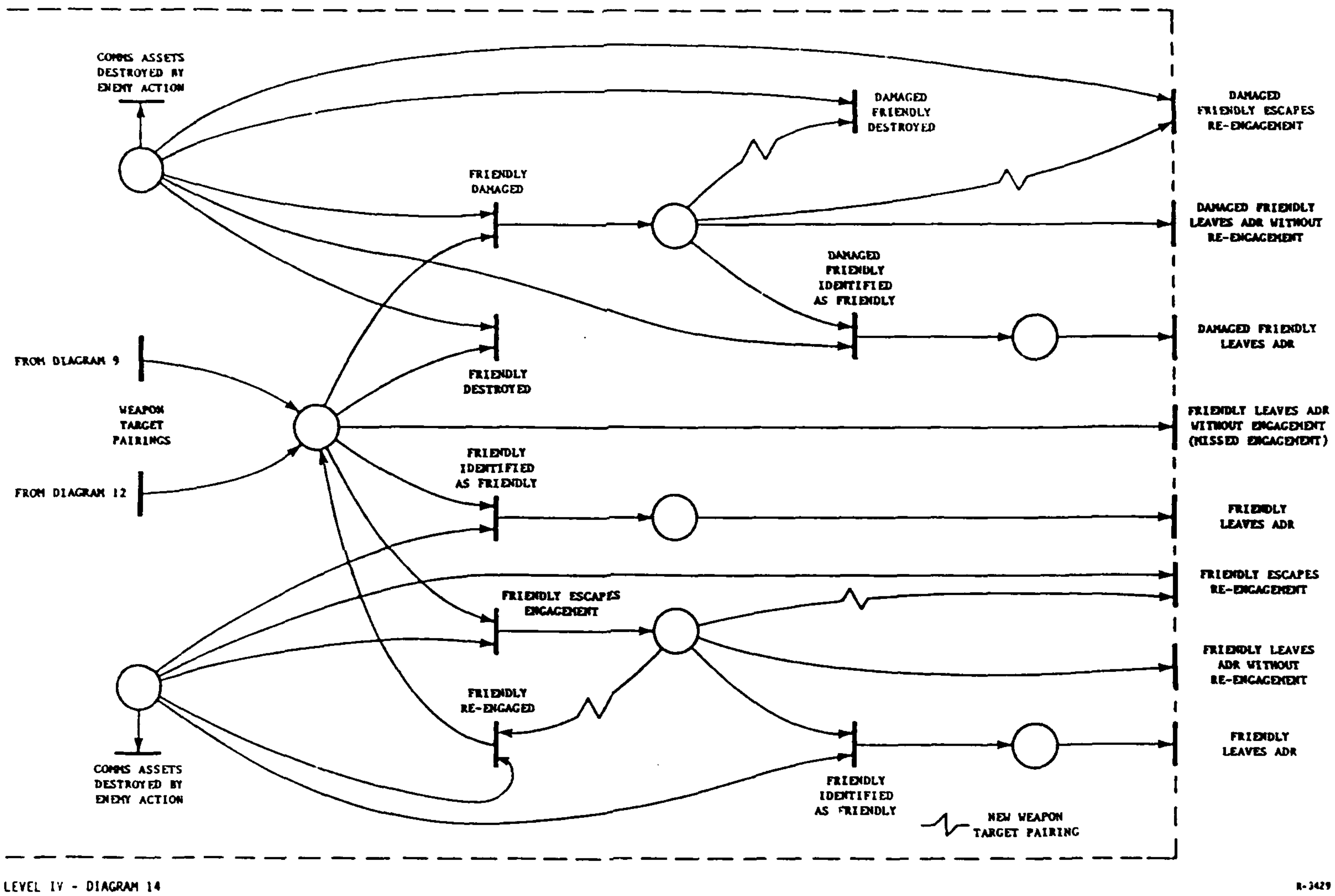


Figure 4-15. Level IV - Diagram Fourteen

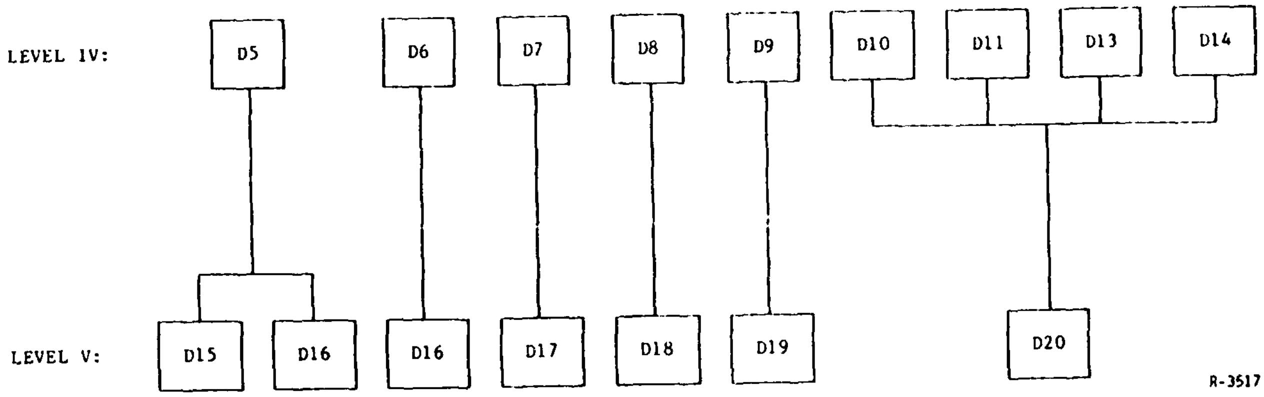


Figure 4-16. Relationships Between Diagrams at Level IV and Level V

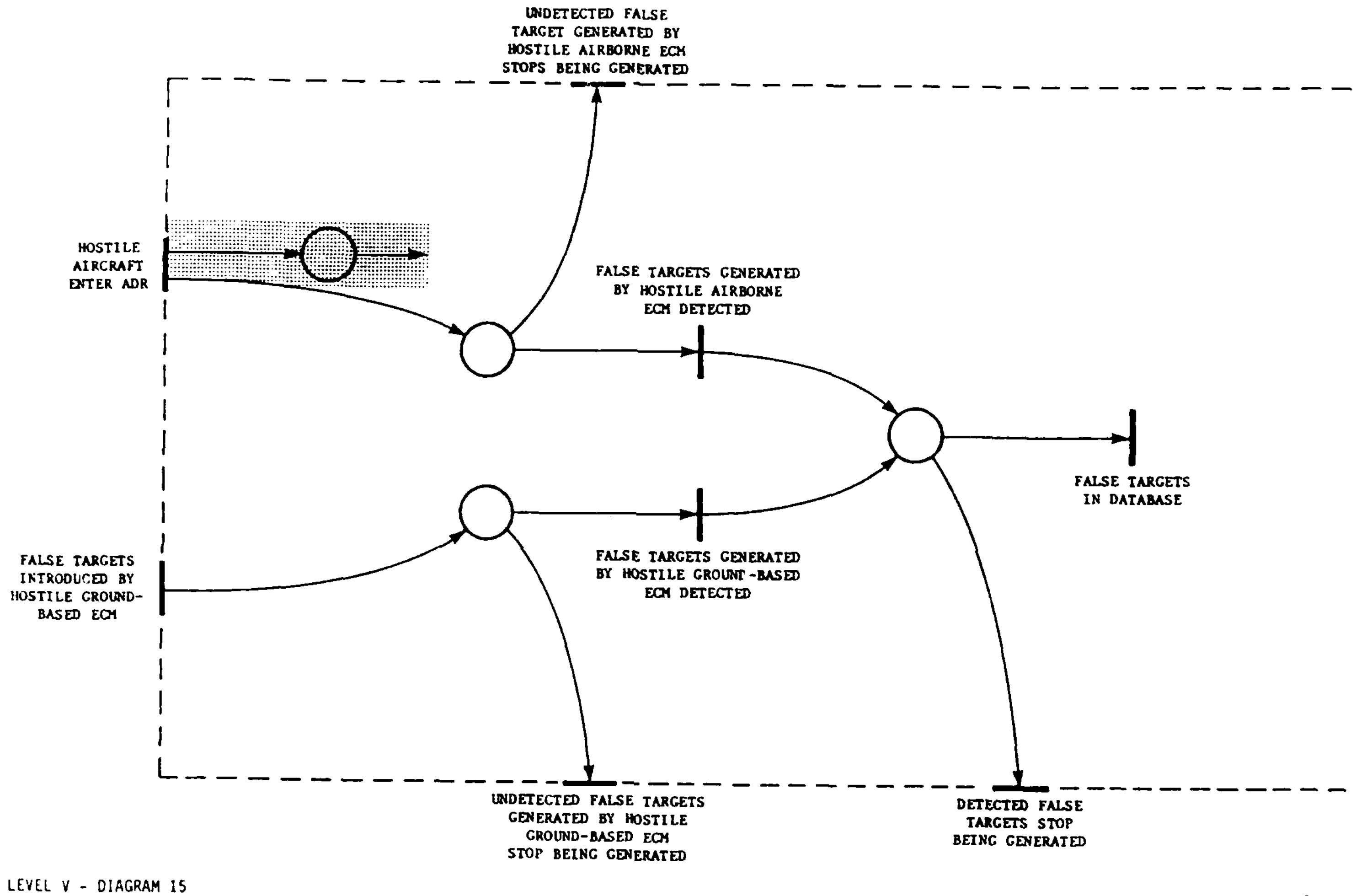


Figure 4-17. Level V - Diagram Fifteen

beyond the FEBA will also generate false targets. These false targets will die away at a rate determined by the nature of the false target generation (jamming, chaff, decoys, etc.).

If false targets continue to be propagated, they may be detected by the air surveillance assets of the air defense system. Note that the two arc-transition-delay combinations associated with detection in Diagram Fifteen, each represent three arc-transition-delay combinations relating to the type of air surveillance asset used in detection. These three combinations are discussed more explicitly in Diagram Sixteen. For simplicity, we combine the two populations of false targets, those generated by hostile airborne ECM and those generated by hostile ground-based ECM, into one population upon detection.

4.6.2 Diagram Sixteen

Diagram Sixteen presents more details of the detection process; the diagram indicates that targets may be detected by Electronic Support Measures (ESM), by active sensors, such as radar, or by other surveillance assets which can be identified in further detail where needed. As before, the dotted line means that the surveillance assets remain available as targets are detected, but some assets must be available for the detections to occur.

Diagram Sixteen represents the detection by the individual air surveillance assets of five classes of targets. The targets being detected are post-mission hostile aircraft, pre-mission hostile aircraft, false targets generated by hostile airborne ECM, false targets generated by hostile ground-based ECM, and friendly aircraft. As in Diagram Fifteen, the two populations of false targets, those generated by hostile airborne ECM and those generated by hostile ground-based ECM, are combined into a single population upon detection.

4.6.3 Diagram Seventeen

Diagram Seventeen presents more details of the identification process. In this representation a target may be identified by nationality (i.e., Friend, Foe, or Neutral) by electronic (cooperative or non-cooperative) means, by procedural methods (essentially clerical means), or by consulting outside sources, such as Intel, other command posts, etc.

The electronic means available to the air defense system for target identification include ESM assets, IFF assets (transponders such as Mark XII), and radio; again, the dotted line means that there assets remain available as targets are identified but some asset must be available for identification to occur. These different assets can be represented separately as needed.

The target may be identified because its flight matches the characteristics of some target on a list of expected targets. In the tactical situation the Movements and Identification (M&I) section keeps a database of recorded

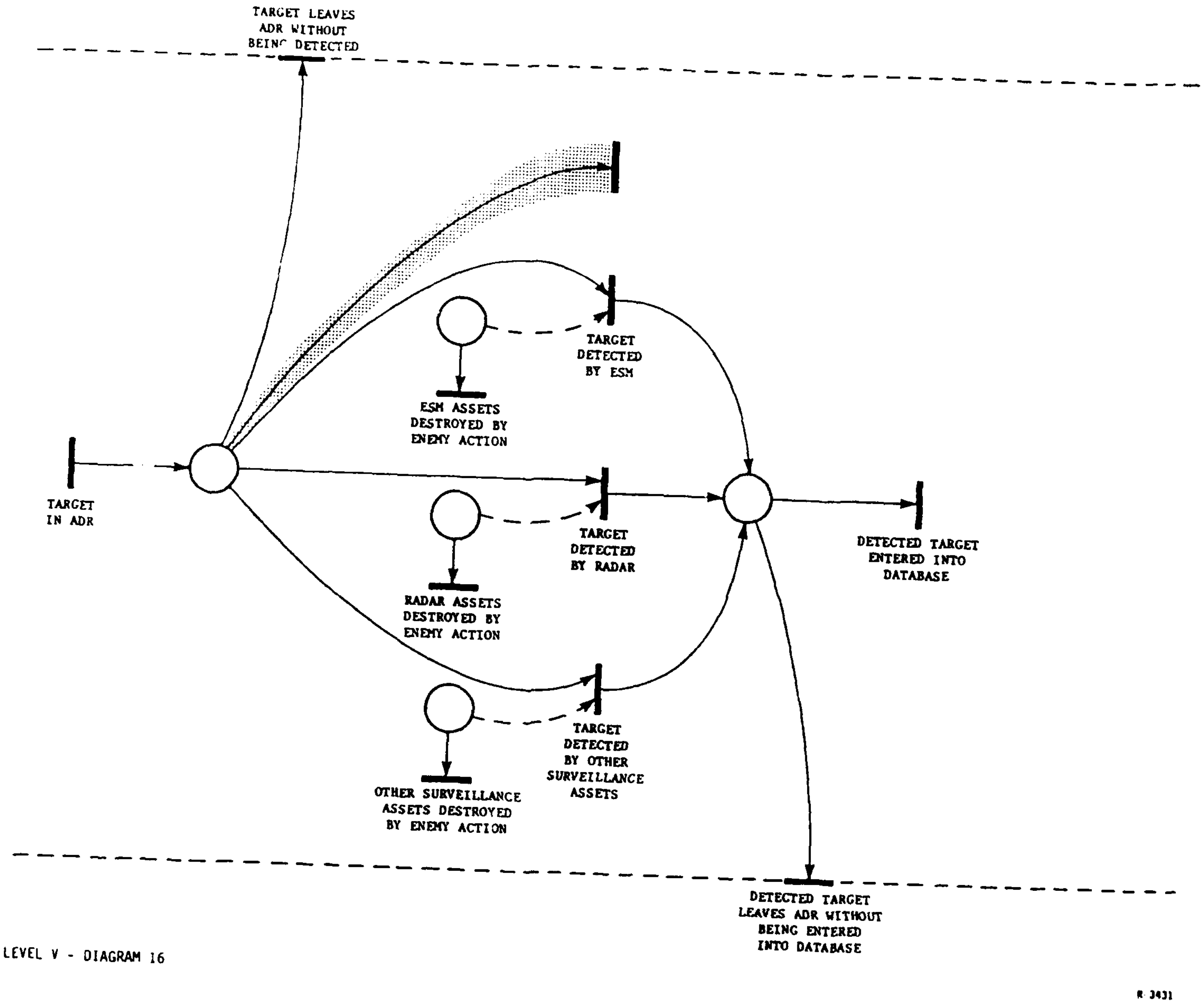


Figure 4-18. Level V - Diagram Sixteen

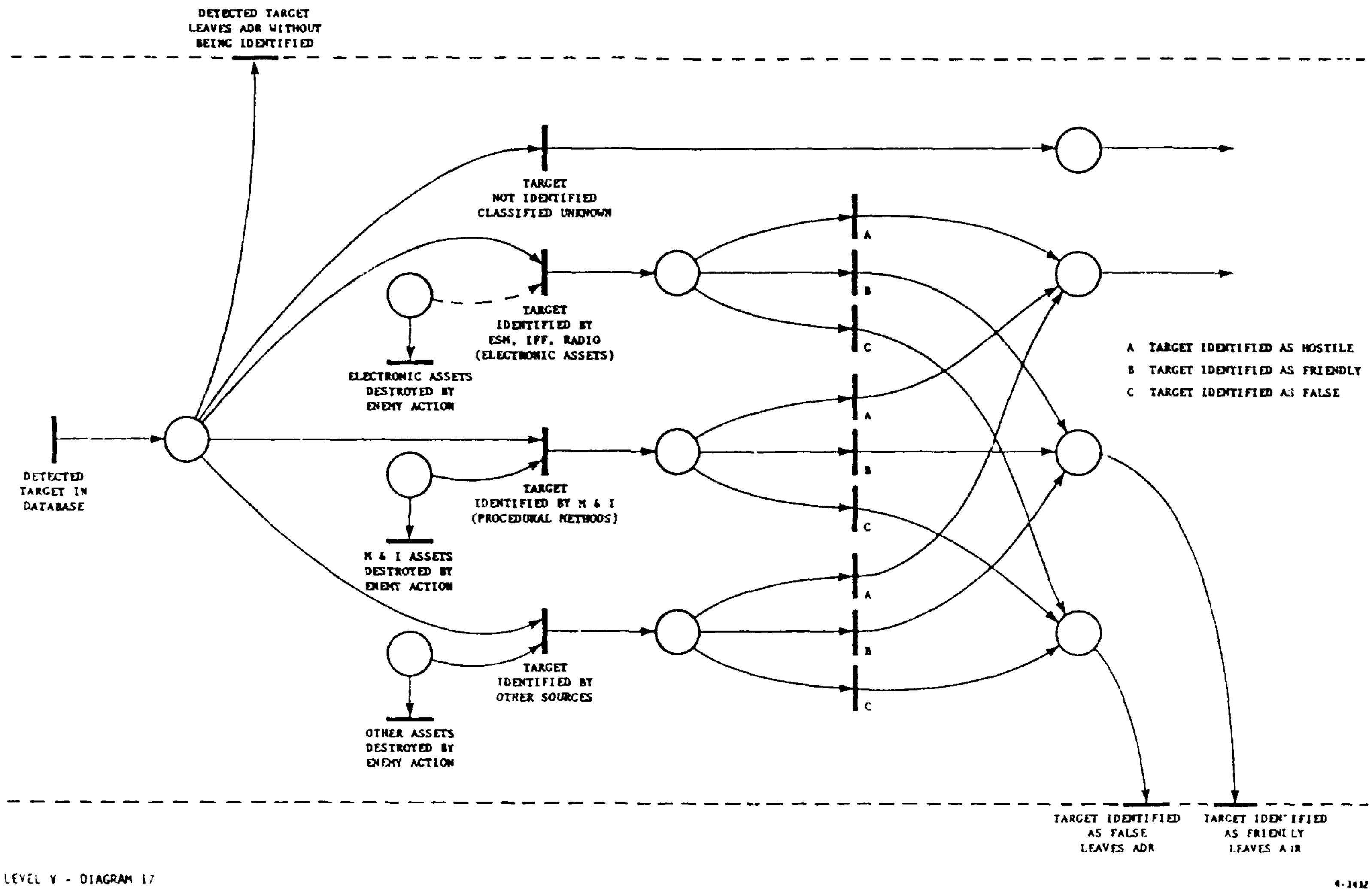


Figure 4-19. Level V - Diagram Seventeen

flight plans, safe corridors, emergency flight patterns, etc., of friendly aircraft. We represent all of this data as a list of expected targets; if the actual target matches some expected target the aircraft is identified.

Likewise intelligence sources may have information on expected targets; again, if the flights match, the target is identified.

In this representation, if a target is not identified by any resource, it goes forward as an unknown. Depending on the Rules of Engagement, an unidentified target might be designated hostile.

This representation assumes that the probabilities (proportions) of identification into the different classes will be different for each resource. (Thus M&I would identify friendly targets almost entirely, as would IFF and radio. ESM might identify mainly hostile targets, etc.).

Note that a target may "leave the system" before it is identified either by physically leaving the region or because the system loses the target track. Finally, note that at this level, if a target is identified as friendly, whether it is or not, it eventually leaves the system and no further processing is done. Diagram Seventeen represents the identification of four groups of targets: post-mission hostile aircraft, pre-mission hostile aircraft, false targets, and friendly aircraft.

4.6.4 Diagram Eighteen

Diagram Eighteen is similar to Diagram Seventeen and represents the common ways a target identified as hostile or unknown can be identified by type; it may be identified by ESM assets, by other non-cooperative techniques, or by other sources. As before, the dotted line means that the electronic assets are necessary for those identifications to occur but do not become unavailable as identifications do occur; information from other sources is represented as a list of expected targets.

The attempt to identify the target by type may conclude that the target is a false target or that it is in fact friendly; otherwise it will be identified as a bomber or a fighter. [These classifications should be seen as illustrative; others, e.g., cruise missiles or helicopters, can be introduced as needed]. This representation assumes that a target that cannot be identified by type will be assumed to be a bomber.

Diagram Eighteen represents the identification by type of eight groups of targets: post-mission hostile aircraft identified as unknown, pre-mission hostile aircraft identified as unknown, false targets identified as unknown, friendly aircraft identified as unknown, post-mission hostile aircraft identified as hostile, pre-mission hostile aircraft identified as hostile, false targets identified as hostile, and friendly aircraft identified as hostile.

Note that the transition entering Diagram Eighteen represents one transition for each of the first four groups of targets; specifically, targets not

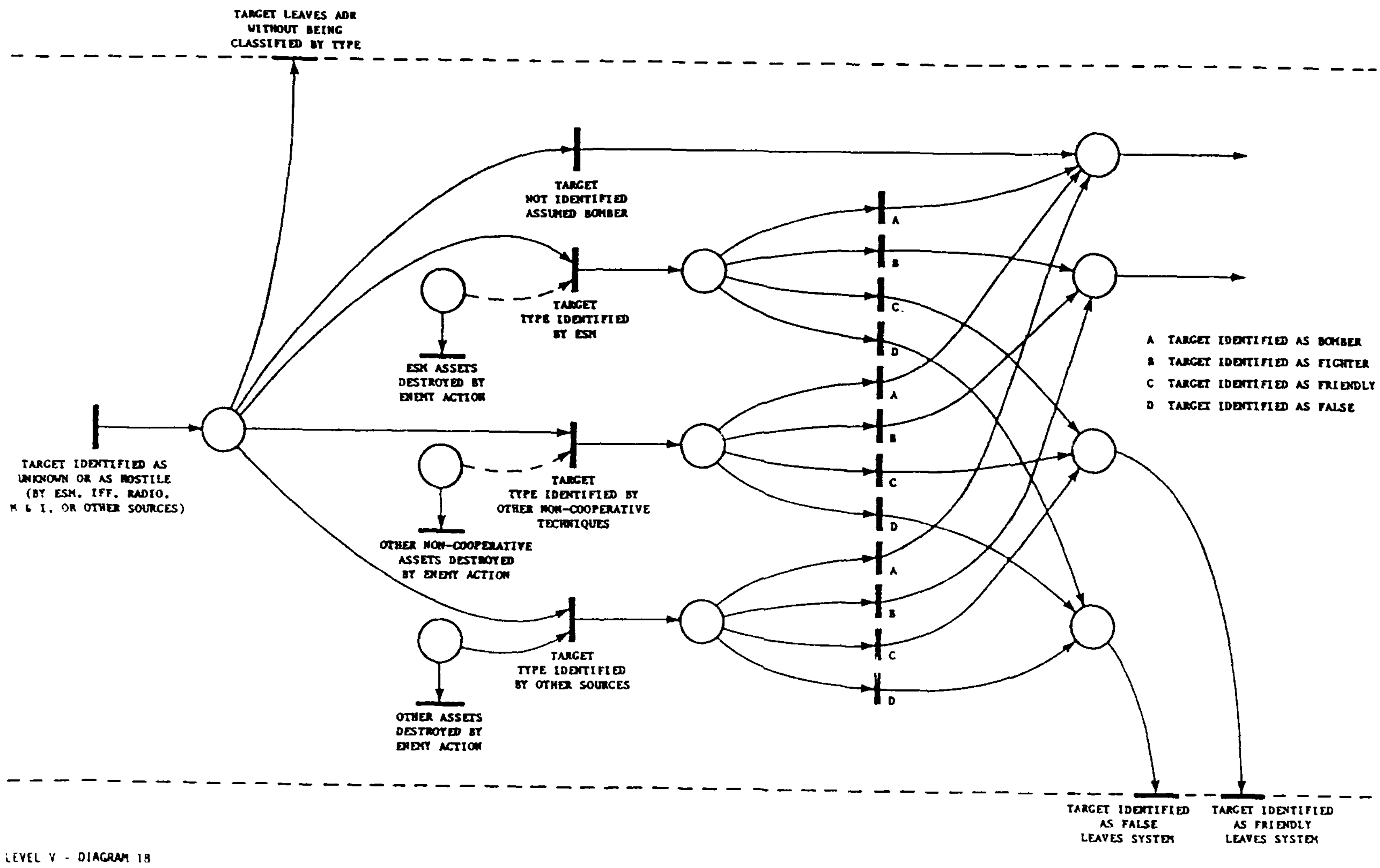


Figure 4-20. Level V - Diagram Eighteen

identified by air defense assets and thus classified as unknown. For each of the second four groups of targets, however, it represents three transitions; specifically, identified as hostile by ESM, identified as hostile by other non-cooperate techniques, and identified as hostile by other sources. Concomitantly, there is one set of delays associated with this transition for each of the first four target groups and three sets of delays for each of the last four target groups.

4.6.5 Diagram Nineteen

Diagram Nineteen presents further detail about weapon-target pairing. A target will either be assigned to a friendly interceptor or to an available SAM site. This representation makes no attempt to indicate how the allocation will be made. The Rules of Engagement (ROE) may specify which is the preferred allocation for some targets: for example, in some situations an unknown target would always be paired with a friendly interceptor, to avoid the possibility of fratricide.

Diagram Nineteen represents weapon-target pairings for sixteen groups of targets: post-mission hostile aircraft identified as unknown bombers, pre-mission hostile aircraft identified as unknown bombers, false targets identified as unknown bombers, friendly aircraft identified as unknown bombers, post-mission hostile aircraft identified as hostile bombers, pre-mission hostile aircraft identified as hostile bombers, false targets identified as hostile bombers, friendly aircraft identified as hostile bombers, post-mission hostile aircraft identified as unknown fighters, pre-mission hostile aircraft identified as unknown fighters, false targets identified as unknown fighters, friendly aircraft identified as unknown fighters, post-mission hostile aircraft identified as hostile fighters, pre-mission hostile aircraft identified as hostile fighters, false targets identified as hostile fighters, and friendly aircraft identified as hostile fighters.

Note that there are four entering transitions for bombers and three for fighters. This is due to the assumption made in this representation that targets not identified by type are assumed to be bombers. Likewise, there is a fourth set of time delays associated with bombers.

4.6.6 Diagram Twenty

Diagram Twenty presents greater detail of the engagement between an air defense weapon and a target. In this representation there are six possible outcomes: the weapon damages the target, the weapon destroys the target, both the weapon and target escape the engagement, a missed engagement occurs (weapon and target remain undamaged), both weapon and target are destroyed, and the target destroys the weapon. In the first four cases, the air defense weapon becomes available for further weapon-target pairings after some delay required for the logistics cycle.

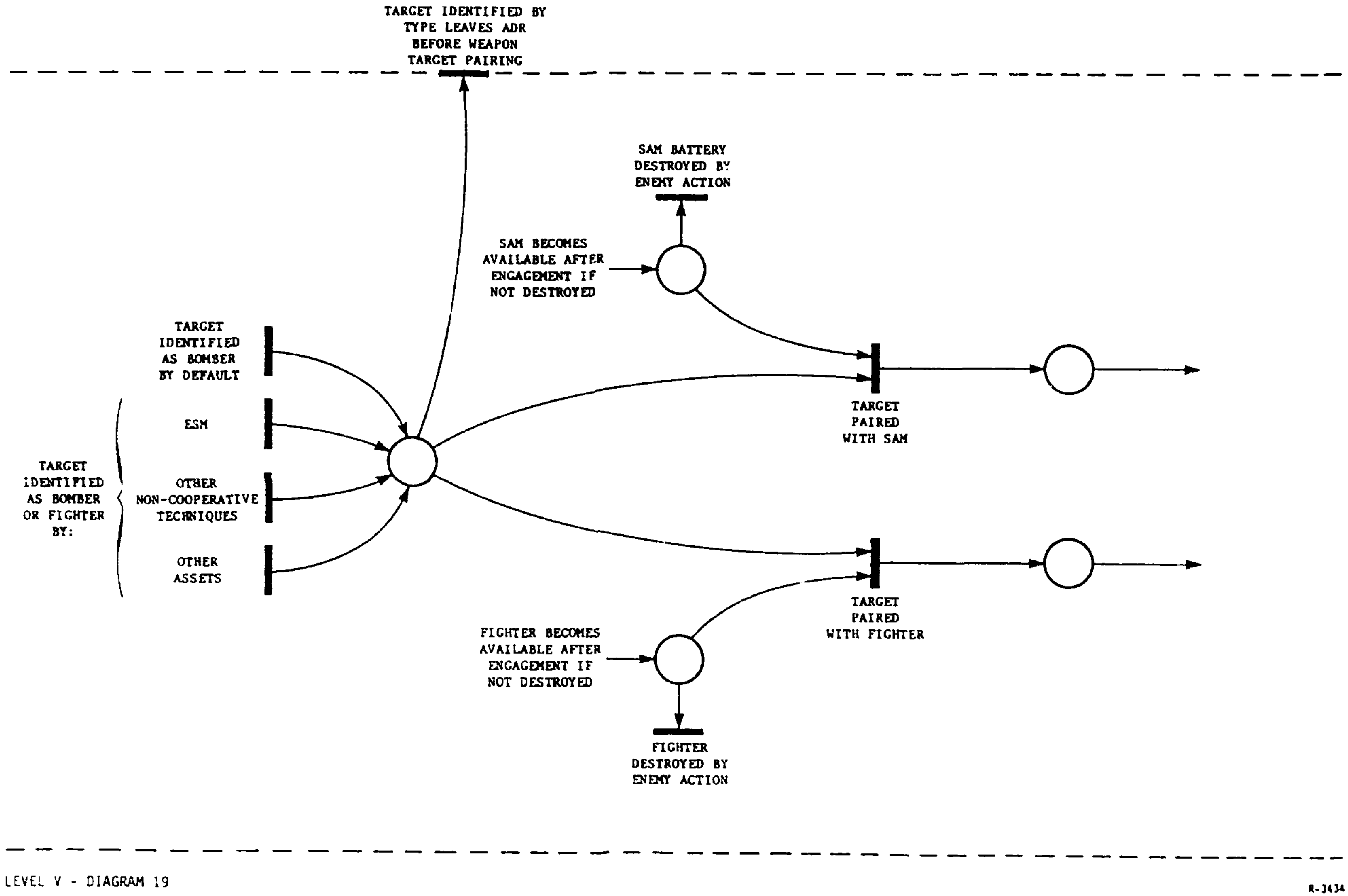


Figure 4-21. Level V - Diagram Nineteen

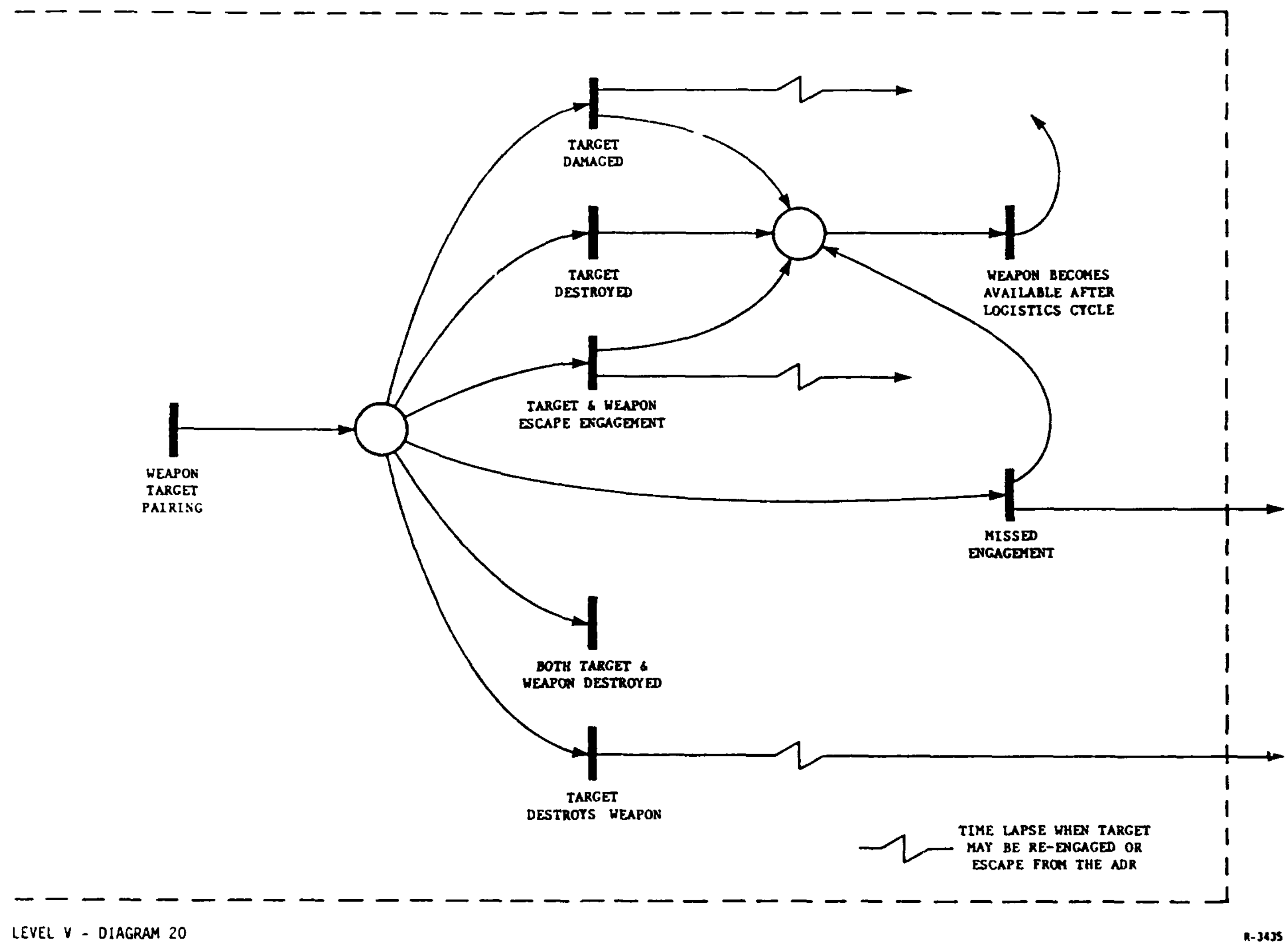


Figure 4-22. Level V - Diagram Twenty

Note that for false targets the fourth outcome (i.e., missed engagement) is the only possible outcome. This will be indicated by appropriate probabilities. The obvious significance of such an event is that it results in the introduction of added time delays in the command and control process as well as increased system load and waste of resources.

Diagram Twenty represents engagements for thirty-two groups of targets: post-mission hostile aircraft identified as unknown bombers and paired with SAM batteries, pre-mission hostile aircraft identified as unknown bombers and paired with SAM batteries, false targets identified as unknown bombers and paired with SAM batteries, friendly aircraft identified as unknown bombers and paired with SAM batteries, post-mission hostile aircraft identified as hostile bombers and paired with SAM batteries, pre-mission hostile aircraft identified as hostile bombers and paired with SAM batteries, false targets identified as hostile bombers and paired with SAM batteries, friendly aircraft identified as hostile bombers and paired with SAM batteries, post-mission hostile aircraft identified as unknown bombers and paired with fighters, pre-mission hostile aircraft identified as unknown bombers and paired with fighters, false targets identified as unknown bombers and paired with fighters, friendly aircraft identified as unknown bombers and paired with fighters, post-mission hostile aircraft identified as hostile bombers and paired with fighters, pre-mission hostile aircraft identified as hostile bombers and paired with fighters, false targets identified as hostile bombers and paired with fighters, friendly aircraft identified as hostile bombers and paired with fighters, post-mission hostile aircraft identified as unknown fighters and paired with SAM batteries, false targets identified as unknown fighters and paired with SAM batteries, friendly aircraft identified as unknown fighters and paired with SAM batteries, post-mission hostile aircraft identified as hostile fighters and paired with SAM batteries, pre-mission hostile aircraft identified as hostile fighters and paired with SAM batteries, false targets identified as hostile fighters and paired with SAM batteries, friendly aircraft identified as hostile fighters and paired with SAM batteries, post-mission hostile aircraft identified as unknown fighters and paired with fighters, pre-mission hostile aircraft identified as unknown fighters and paired with fighters, false targets identified as unknown fighters and paired with fighters, friendly aircraft identified as unknown fighters and paired with fighters, post-mission hostile aircraft identified as hostile fighters and paired with fighters, pre-mission hostile aircraft identified as hostile fighters and paired with fighters, false targets identified as hostile fighters and paired with fighters, and friendly aircraft identified as hostile fighters and paired with fighters.

4.7 SUPPLEMENTARY DIAGRAMS

Diagrams Twenty-one through Twenty-three represent processes that occur at various places throughout the hierarchy of the air defense system. For simplicity, we excluded these processes in the foregoing discussion. We include them here for completeness. As discussed below, these diagrams may be thought of as overlays to various sections of the diagrams in Levels I - V.

4.7.1 Diagram Twenty-One

Diagram Twenty-one shows that the process of communication requires communications resources; when communication is complete the resources again become available. Resources may also be unavailable due to hostile jamming, which we represent as the capability to disable a given number of communications assets. These assets become available again when jamming ceases or when ECCM is successfully applied.

This diagram applies equally to voice communication or to data communication, and may be thought of as an overlay whenever a population of communications assets occurs.

4.7.2 Diagrams Twenty-Two and Twenty-Three

In the foregoing discussion, the surface-to-air missiles (SAMs) were implicitly assumed to be high-and-medium-altitude surface-to-air missiles (HIMADs), such as HAWK or PATRIOT. These are the missile batteries that operate semi-autonomously, having a data link to the Control and Reporting Center (CRC) of the air defense system. That is, the air situation picture that is maintained by the surveillance subsystem of the air defense system is available to the operators of these weapons systems.

There is another class of surface-to-air missiles intended for short range air defense (SHORAD). These are a diverse group of weapons, shoulder-mounted, such as STINGER, jeep-mounted, etc., that move with the ground troops they are defending. These missiles have no data link to the air picture being maintained by the CRC; they are sometimes allocated targets by voice communications, but generally they operate autonomously, attacking aircraft that appear to have hostile intent.

Diagram Twenty-Two

Diagram Twenty-two (a) shows that any population of aircraft is potentially subject to engagement by SHORAD surface-to-air missiles. The engagement may have the same set of four outcomes as shown in Diagram Twenty. Diagram Twenty-two (b) shows a much simpler representation of the same process: if the model being developed has no need to keep track of SHORAD assets, then we may represent any population of aircraft as being destroyed at some rate by SHORAD resources. Diagrams Twenty-two (a) and (b) may be thought of as overlays on higher level diagrams wherever a population of aircraft appears.

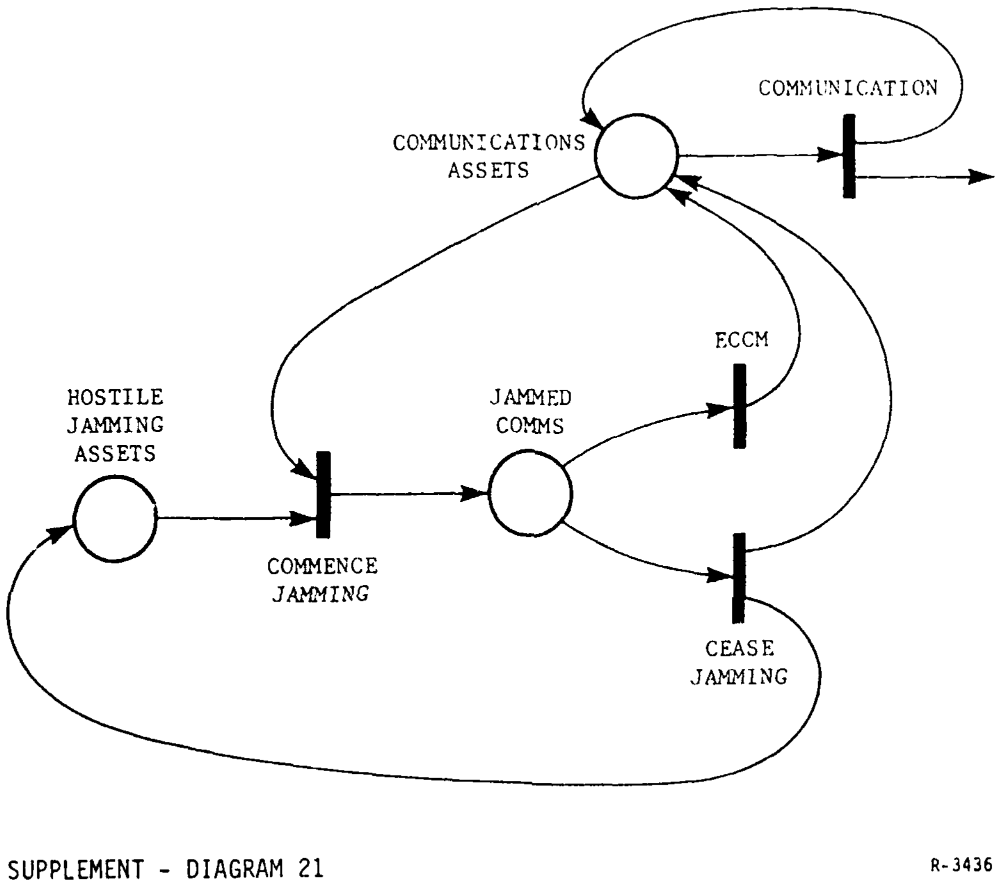
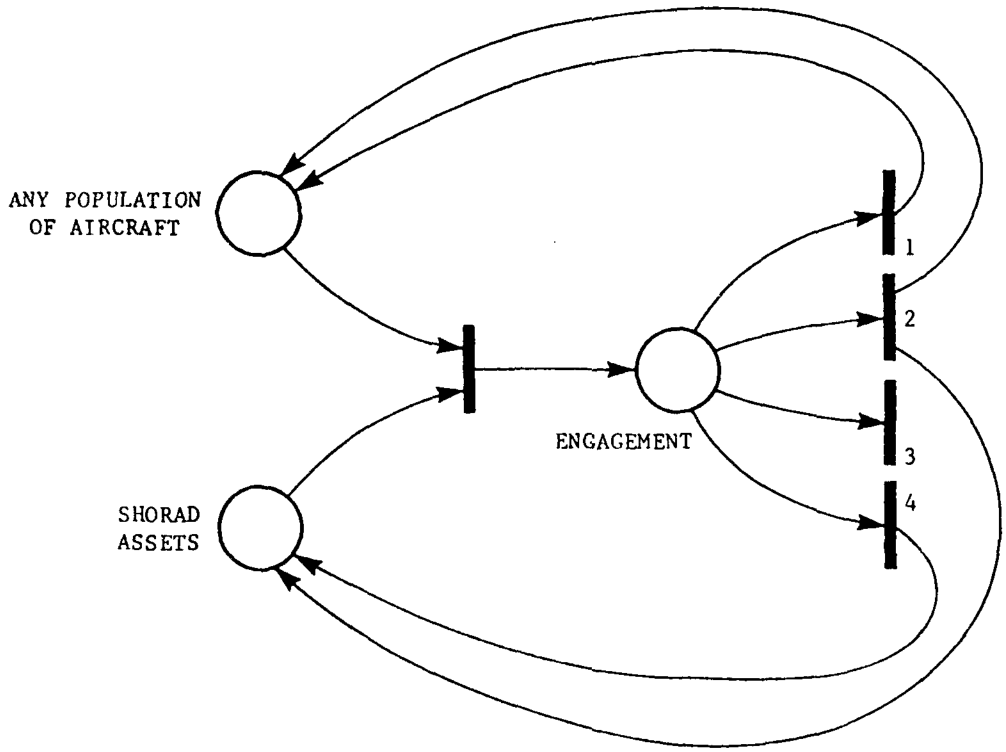
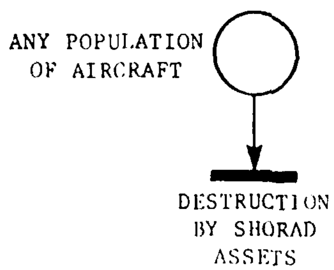


Figure 4-23. Supplement - Diagram Twenty-One



1) AIRCRAFT DESTROYS SHORAD RESOURCE
2) BOTH AIRCRAFT & SHORAD RESOURCE ESCAPE
3) BOTH DESTROYED
4) SHORAD RESOURCE DESTROYS AIRCRAFT

SUPPLEMENT - DIAGRAM 22a R-3514



SUPPLEMENT - DIAGRAM 22b R-3515

Figure 4-24. Supplement - Diagram Twenty-Two (a & b)

Diagram Twenty-Three

Diagram Twenty-three illustrates the more complicated situation that occurs when SHORAD assets engage (autonomously) aircraft that are already subject to weapons-target pairing. In this representation it is assumed that the SHORAD assets are not destroyed as a result of the engagement. There are then three possible outcomes. If the SHORAD destroys the target, the weapon which was allocated to that target will still attempt to engage the target; the result will appear to be a missed engagement. If the SHORAD destroys the weapon (this probability is greater than zero only when the weapon is a fighter), then the result may appear to be an engagement in which the target destroyed the air defense weapon. Finally, if the SHORAD destroys neither, then the engagement between the target and the weapon allocated by the air defense system will continue as before. Diagram Twenty-three may be thought of as an overlay to Diagrams Ten, Eleven, Thirteen, and Fourteen, as well as Diagram Twenty.

4.7.3 Representation of Human Activities in Air Defense

Note that it is not until we decompose to Level V and beyond that it becomes possible to consider detailed human activities. For example, in Diagram Nineteen (Fig. 4-21), the transition "target paired with fighter" could be further decomposed based on various ways in which the pairing (Process) might be accomplished to achieve minimum "leakage" (Goal) and the characteristics of the Target/Weapon Assignments Officer (Resource), his degree of authority and required coordination (Organization), and the relevant displays, controls, processing equipment, and decision aids (Resources) at his disposal. A sub-network would be constructed at this point, based on available data and assumptions about how the function is (or is to be) accomplished, to represent the detailed human-system interaction.

4.8 MINIMAL INDEPENDENT SET OF MEASURES FOR HIERARCHY

4.8.1 Introduction

In the preceding subsections we presented a five-level hierarchical representation of an air defense system in Petri net diagrams based on the method of Section 3 and Appendix A. In addition, in Appendix B we presented a general method for generating all canonical measures associated with a Petri net diagram. Applying the method of Appendix B to the hierarchy in the preceding subsection yields a reasonable number of measures for Level I: there are four probabilities, six rates, four occupancies and six delays. Subsequent levels present the system in greater detail, so that at Level IV there are much larger numbers of measures; at Level IV there are 253 probabilities, 193 rates, 129 occupancies and 348 delays.

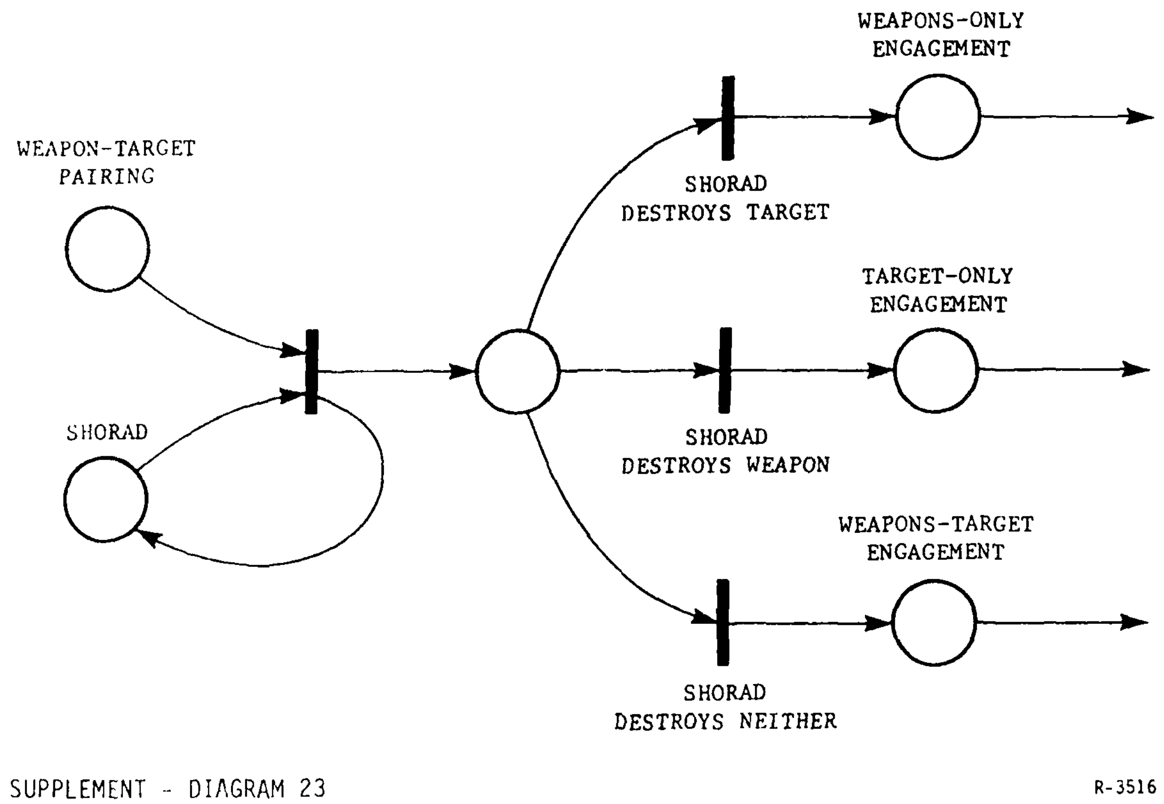


Figure 4-25. Supplement - Diagram Twenty-Three

Fortunately, as discussed in Appendix B, it is relatively straightforward to derive an independent set of primary measures. This set is complete, in the sense that all measures can be derived from this independent set, and minimal, in the sense that all measures cannot be derived from any lesser set. The reduced set can be dealt with more efficiently. Subsection 4.8.2 discusses the derivation of the independent and minimal set for any Petri net. Subsections 4.8.3 through 4.8.6 present the independent set for Levels I through IV.

4.8.2 Derivation of Minimal Set

There are actually two ways to derive a minimal and independent set of measures for each level of the hierarchy. The first method involves deriving the dependencies at each level (the horizontal relationships) and using these to eliminate the dependent variables. This method was used for Levels I, II and III. The dependencies are given in the Appendix, as are definitions for all the measures at each level.

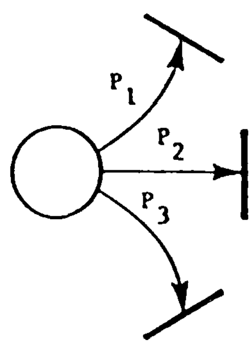
The following presents a more general method, which discusses which measures may be dropped from the complete set of measures that results from a Petri net representation of a system.

Delays

All delays are independent, none may be dropped from the complete set of measures.

Probabilities

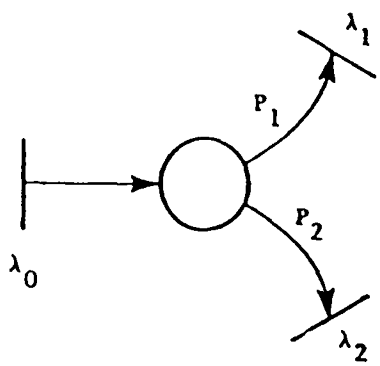
When more than one arc leaves a place then one of the probabilities associated with the set of arcs can be expressed in terms of the others and may be dropped.



$$P_1 = 1 - (P_2 + P_3)$$

Rates

All rates that can be expressed as the product of an upstream rate and a probability, can be dropped.

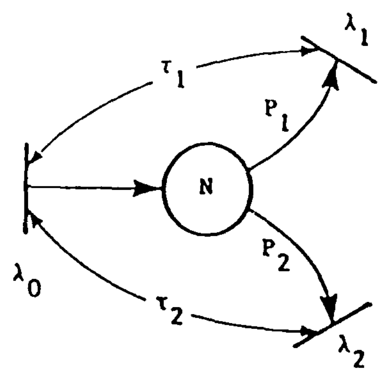


$\lambda_1 = P_1 * \lambda_0$

$\lambda_2 = P_2 * \lambda_0$

Populations

We may omit all populations which can be recovered from delays, rates and probabilities.



$N = (P_1*\tau_1 + P_2*\tau_2) * \lambda_0$

4.8.3 Level I

Figure 4-26 shows the diagram for Level I, Diagram One (Fig. 4-1), with all measures indicated. From the full set of Level I measures, we suggest the following subset of selected independent measures. Where we have a choice between measures to omit, we use the "more-is-better" rule of thumb where possible. That is, given a choice between two related measures, we choose the measure that if increased implies that the system is improving.

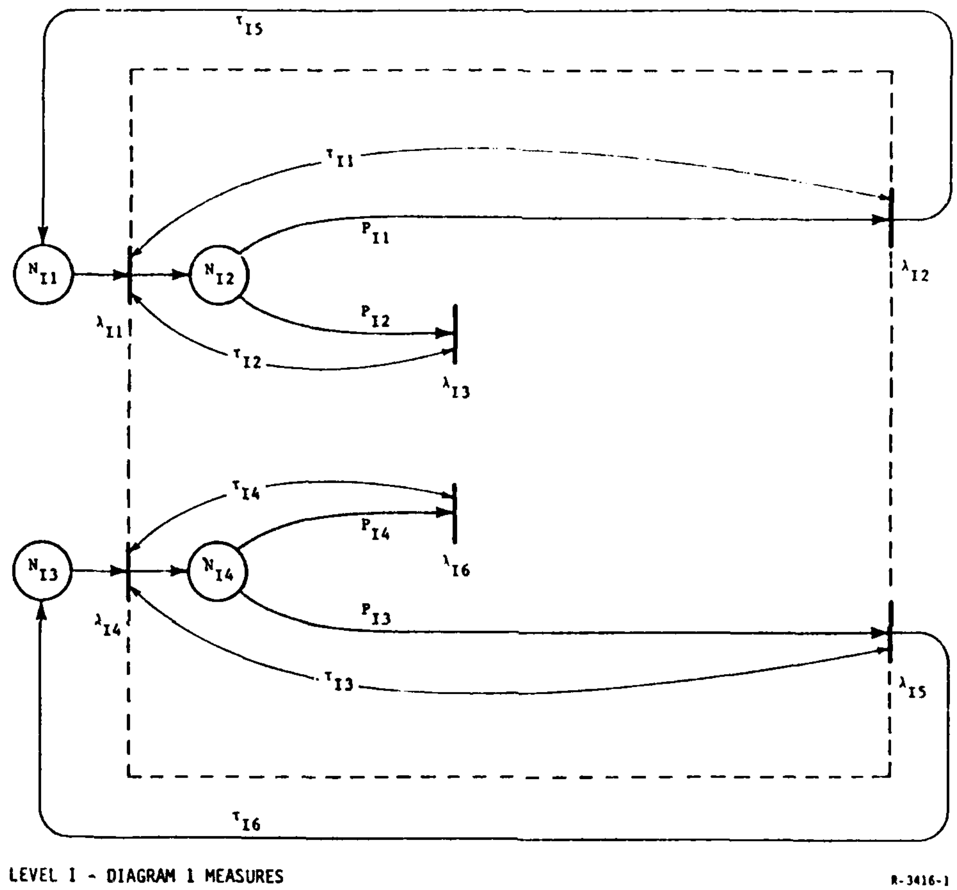


Figure 4-26. Measures at Level I

Mission Parameters

T: The time period of the mission, in hours.

λ_{I1}: The arrival rate of hostile aircraft into the air defense region (ADR).

λ_{I2}: The arrival rate of friendly aircraft into the ADR.

Measures of Effectiveness

P_{I2}: The probability that a hostile aircraft will be destroyed by the air defense system, given that it has entered the ADR.

P_{I3}: The probability that a friendly aircraft will exit the ADR, given that it has entered the region.

τ_{I2}: The average delay between the time a hostile aircraft enters the ADR, and the time it is destroyed by the air defense system, given that it is destroyed.

τ_{I4}: The average delay between the time a friendly aircraft enters the ADR, and the time it is destroyed by the air defense system, given that it is destroyed.

A complete set of measures for all five levels has been derived, along with the relationships among the measures at the different levels (Moore et al., 1986). Suffice it to say that the values for the measures of effectiveness at the top level can be derived directly by aggregation from the most detailed levels, as described in Section 3.

SECTION 5

LESSONS LEARNED

As presented in Sections 2, 3 and 4 of this report, trial applications of various elements of IAT were made to SIMCOPE, a simulated C^3 subsystem; to the NORAD Missile Warning Center; and to a generic Air Defense System. These applications resulted in critical "lessons learned," which are summarized below:

During the SIMCOPE application, an attempt was made to use the SHOR paradigm (Wohl, 1981) as the basis for system description and decomposition. This attempt was unsuccessful, and both $IDEF_0$ and Data Flow Diagrams (DFDs) were resorted to, with the latter ultimately being used as the primary representational scheme because of its relative simplicity and clarity. (See Appendix D for procedures and guidelines for using DFDs to develop IAT data.)

In addition, the SIMCOPE application involved only skill- and rule-based behavior ((Rasmussen and Rouse, 1979); see Volume I for description of this taxonomy). Since no knowledge-based behavior was required of the operator, his tasks in SIMCOPE were not truly representatative of human decisionmaking tasks in C^3 systems. Nonetheless, it was possible to demonstrate the application of queuing theory methods to system performance analysis and prediction.

In contrast to SIMCOPE, the NORAD Missile Warning Center application was a completely realistic one. Data Flow Diagrams once again were used for system description and decomposition, in this instance down to the third level of detail. This application uncovered the fact that many of the processes involving human activities are procedure-bound; that is, they are governed largely by checklists, written procedures, unwritten procedures, and informal "arrangements" among crew members. Fortunately, much of this was found to be routine and rule-based, and therefore easily modeled. While the data amassed during this application could support several types of analyses, only the simplest of PERT/CPM analysis methods was considered in this case.

Another lesson learned at NORAD was the fact that at these higher levels of command authority and responsibility, a great deal of human activity is involved in briefing; that is, in aggregating or packaging (chunking) information for easier and more rapid "digestion" at the next higher level of command. This almost always involved situation assessment and hypothesis formulation, as well as option identification activities. The briefing would then take the form of "Here's the situation, here's what we think is happening, here's the status of our own systems and forces, here are the things we can do, and here's what looks best under the circumstances."

The main difficulty for the analyst at NORAD was in extracting the unwritten procedures from the crew members, i.e., the things that they do "automatically" as a trained crew or "expert team." This required that the analyst be, in effect, a "knowledge engineer." Without the aid of the sophisticated artificial intelligence techniques available to trained knowledge engineers, this became a difficult and time-consuming task.

The Air Defense application, which was done partly under the aegis of DCA and JCS, was based on the representational and decomposition requirements described in Volume I of this report. It was also the first attempt to apply the extended Petri net methodology (STAPNs) to a system of realistic capability, complexity, and size, using a completely "top-down" approach.

The results clearly indicated that STAPNs could be used to describe all of the activities in both in C^3 systems and the weapon systems which it controls. The existence of a complete, nested set of measures of both system performance and military effectiveness was also demonstrated.

While the decomposition was taken down to the fifth level, the resulting complexity is exemplified by the approximately 1000 measures identified (Moore et al., 1986). However, at least one and perhaps as many as three or four more levels of detail would have to be developed in specific subsystem areas in order to provide the requisite information about human decision functions for modeling and prediction purposes. But since such details can be modeled using STAPNs, as shown in Volume I, one would anticipate little or no problem in this regard other than the additional effort required. In any case, there is no shortcut to dealing with the complexity inherent in manned C^3 systems.

All of the applications to date involved manual paper-and-pencil activities, which strongly indicated that the labor-intensiveness of such activities for future applications to C^3 systems would be prohibitive, and that automated aids for IAT would have to be developed. This fact was a major driver in the development of the STAPN representation and modeling approach, as well as the Box Node aggregation primitive and the frame/slot data management technique noted above.

APPENDIX A

THE QUEUING MODEL FOR SIMCOPE

A.1 THE SIMCOPE OPERATIONAL ENVIRONMENT: GOALS/ORGANIZATION/PROCESSES/ RESOURCES

The focus of SIMCOPE is on the Missile Warning Officer (MWO) in the CWC, who receives messages from surveillance systems that monitor missile launch activities ("events"). The MWO must acknowledge messages, determine what the events are associated with the messages, generate reports about the events, and forward them to the Command Defense Center (CDC).

For each detected launch event, there may be three messages:

1. ADS-1 (the first indication from the Advanced Detection System, ADS).

2. ADS-2 (the second indication from ADS).

3. BSS (indication from the Barrier Surveillance System that an object has actually crossed the blue-side coastline).

Other messages of interest describe non-launch events. Note that messages describing system status and intelligence are important, but should be considered independently from the primary processing (message-handling) of launch-related events.

Figure A-1, presented earlier as Fig. 2-2, is included in this Appendix as a reference diagram to show data flow of message handling in SIMCOPE.

A.1.1 Description and Analysis of Mission Events

Figure A-2 portrays the structure of mission events for SIMCOPE. Figure A-3 illustrates how frame notation can be used to describe the overall scenario that drives the system: Attack Warning, Threat Assessment, and Damage Estimation are the three critical components of the scenario.

For purposes of analysis using IAT, no reaction by the enemy has been assumed. Therefore, there are four output events which are generated in an essentially open-loop fashion:

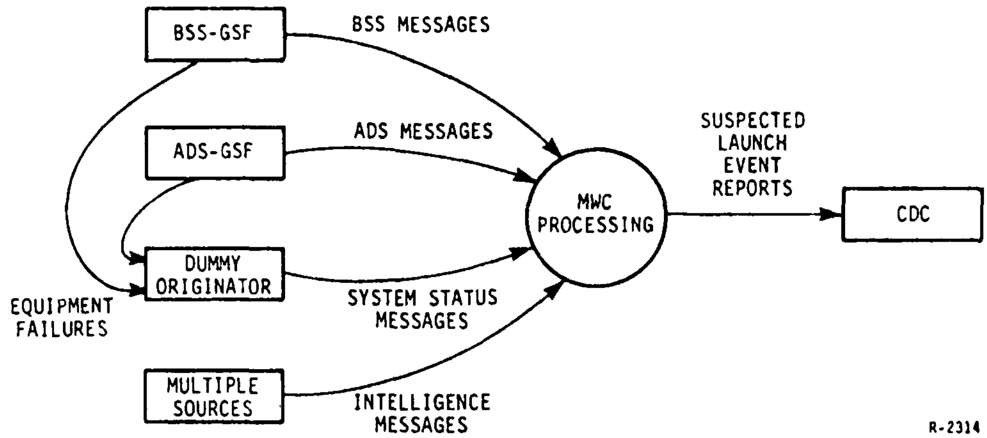


Figure A-1a. DeMarco Diagram Used in SIMCOPE Validation: Context

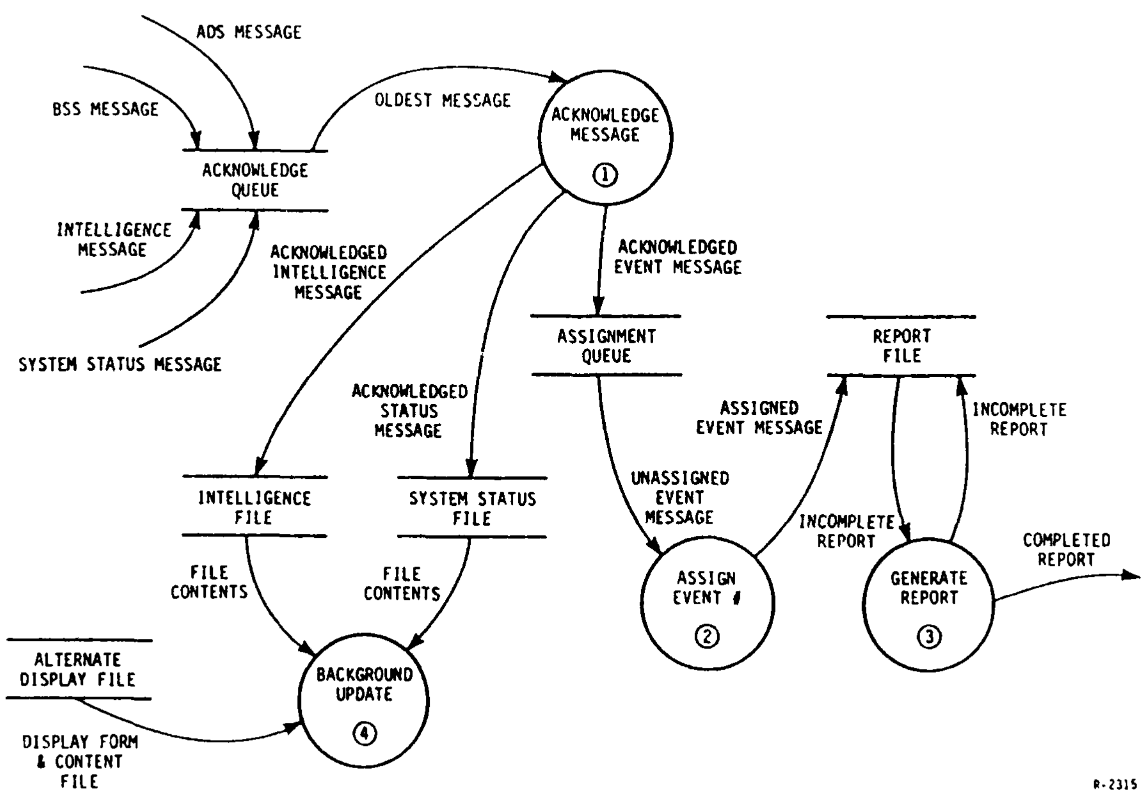


Figure A-1b. DeMarco Diagram Used in SIMCOPE Validation: Overall Data Flow

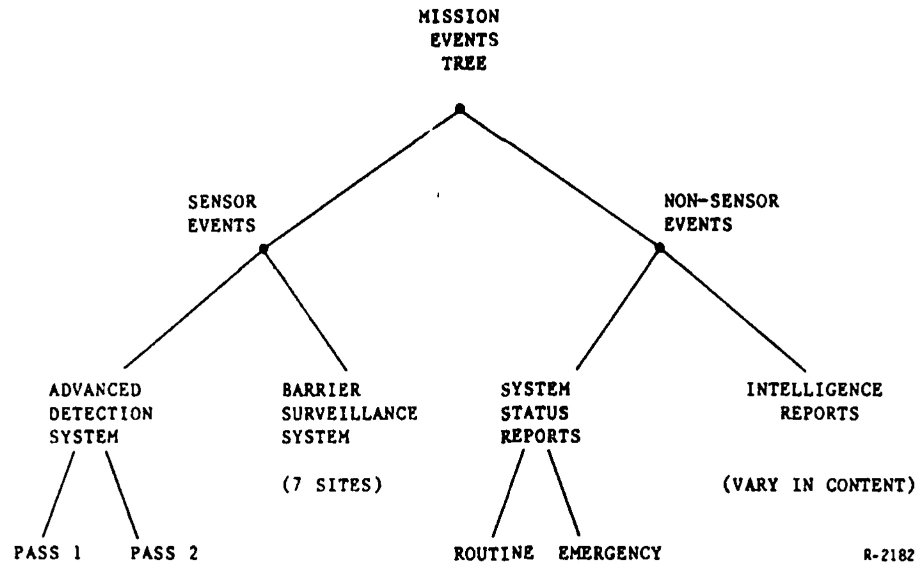


Figure A-2. Tree Structure Showing Mission Events

MISSION FRAME

1)	a.	Scenario Name	1. Attack Warning 2. Threat Assessment 3. Damage Estimation
	b.	System Name:	Command Warning Center (CWC)
	c.	System Type:	Strategic
	d.	Mission Type:	Defensive
2)	a.	Threat Reaction(s):	None
	b.	Type(s) of Reaction(s):	N/A
3)	a.	Preconditions(s)	One
	b.	Condition Name(s)	Mission Phase (Pre-attack)
4)	a.	Contingencies:	Two
	b.	Contingency Type (s):	1. Equipment Outage 2. Spurious Errors in Transmitted Messages
5)	a.	Number of Events(s):	Four
	b.	Event Type(s):	1. Intelligence Reports 2. System Status Reports 3. Suspected Launch Reports 4. Detected Non-Launch Event Reports
6)	a.	Impact(s):	Two
	b.	Consequence Name(s)	1. False Alarms (Inappropriate Attack Warning(s) 2. Missed Attack Warnings
7)	a.	Environmental Factor(s):	Two
	b.	Factor Name(s):	1. Work Environment 2. Combat Stressors

Figure A-3. SIMCOPE Mission Events Frame: Example Showing Use of Frame Notation to Capture Properties of (Mission) Events

1. Intelligence Reports

2. System Status Reports

3. Suspected-Launch Reports

4. Other Sensor Detection Reports

If the prevailing condition in the system is peacetime monitoring, prior to executing the scenario, the four output events listed above are analyzed as "disturbances" to the status quo. Other than changing the prevailing conditions or postulating enemy (threat) reactions, there are only two contingencies which could affect how the four output events are generated:

- Equipment outage(s)
- Erroneous reports or report contents

A.1.2 Consequences of Executing the Mission Scenario

When the scenario is executed, the expected result will be to generate the four reports listed above. However, there are two other types of events that should be noted:

1. Inappropriate Events (false alarms)

2. Undetectable Events (misses)

(There are also mission events which might affect the work environment and the stress level under crisis conditions, but these types of environmental stressors will not be considered in the analysis that follows.)

A.2 ASSUMPTIONS AND STRUCTURE OF THE MODEL

1. Each message stream is a process with an independent Poisson arrival (exponential interarrival time).*

2. The expected value of the arrival rates can be used to characterize each message stream.

3. Data required to establish values for arrival rates can be collected from the SIMCOPE mission environment.

*In the actual SIMCOPE scenario, the three messages would not be strictly independent; arrival of any ADS-1 message would imply that an ADS-2 and possibly a BSS message would be arriving at some future time. These complications are not taken into account in the preliminary analysis presented here.

4. There is a separate server for each process shown in Fig. A-1b.

5. The utilization factor (ρ) for each process remains less than 1.

A.2.1 Expressions to Describe Arrival and Service Rates

Notations for the arrival rates and service rates of interest appear below:

λ_S = Arrival rate for system status messages

λ_I = Arrival rate for intelligence messages

λ_{ADS1} = Arrival rate for ADS1 messages

λ_{ADS2} = Arrival rate for ADS2 messages

λ_{BSS} = Arrival rate for BSS messages

μ_{ACK} = Acknowledge service rate

μ_{ASN} = Assign service rate

μ_{REP} = Report service rate

Given the assumption of Poisson arrivals, the overall message arrival rate for the system is the sum of individual arrival rates:

$$\lambda_A = \lambda_S + \lambda_I + \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS} \quad . \tag{1}$$

Arrival rates for the "Assign" and "Report" queues can be expressed similarly as the sum of message arrival rates, once we observe that:

- Only event-related messages pass to the Assign queue.
- All messages going to the Assign queue also go to the Report queue (see Fig. A-1b for data flow).

Arrival rate for Assign queue:

$$\lambda_{ASN} = \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS} \quad . \tag{2}$$

Arrival rate for Report queue:

$$\lambda_{REP} = \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS} \quad . \tag{3}$$

A.2.2 Expressions to Describe Waiting Times

Since all event messages must pass through all three processes in the system, the time any message might be expected to remain in the system is the sum of the time spent in each process. From expressions (2) and (3) above, and from Table 4-2 in Section 4,

$$W = 1/(\mu_{ACK} - \lambda_A) + 1/(\mu_{ASN} - \lambda_E) + 1/(\mu_{REP} - \lambda_E) \ , \tag{4}$$

where

$$\lambda_E = \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS} \ . \tag{5}$$

A.2.3 Estimating Delays and Queue Length

In the SIMCOPE example considered here, delay in the system can be estimated as the sum of the expected service times:

$$1/\mu_{ACK} + 1/\mu_{ASN} + 1/\mu_{REP} \ . \tag{6}$$

This estimate assumes only one "critical path" -- viz., through all three processes. An alternative method to predict delays would use an event analysis or CPM (Wohl, 1984). However, the queuing theory analysis used in (6) above is preferred: if the arrival rates are small compared to the service rate, both the CPM and the queuing estimates would be comparable; but when capacity is highly loaded (arrival rates exceed service capabilities), the CPM approach would underestimate the expected values.

The backlog of reports, or expected number of reports in the Report queue, provides a description of queue length:

$$L = \lambda_E/(\mu_{REP} - \lambda_E) \ . \tag{7}$$

An efficient system should have a small backlog (L should be low compared to other parameter values). Note, however, that it is often extremely costly, in terms of number and speed of servers, to maintain a low value of L over long periods of continuous service.

A.3 DETERMINING SERVICE RATES: USING INFORMATION FROM THE STRUCTURAL MODEL

The problem of estimating and predicting service rates is critical for predicting human/system performance. Questions of operator control and attention must be addressed. Control structures, in turn, depend on goals, organizational policies and rules, and human operator capabilities (related to an individual's background and training).

> It is here that the four dimensions (GOALS, ORGANIZATIONS, PROCESSES, RESOURCES) of the IAT structural modeling component become most useful in describing human performance in the SYSTEM.

The problem of deriving service rates presents a clear case for linking information from the structural model to assumptions that are needed to carry through with the queuing theory application.

A.3.1 Assumptions for Determining Service Rates

There are two problems that must be considered in determining service rates:

1. What is the effective rate, given that the same resource must be used in several processes?

2. What is the rate to perform a specific task, given that resource attention is devoted to that task?

The first problem is addressed in the discussion that follows, since it describes the general case for the SIMCOPE example.

The Effective Rate for the Acknowledge Queue

Based on the data flow representations (Figs. 5-5 through 5-7), we shall assume that the conditions listed below describe the SIMCOPE operational environment:

1. Computerized processes are executed much more rapidly than are manual ones.

2. Associated processing delays for computerized processes are negligible, and can be ignored for purposes of presentation here.

3. The human operator controls the movement of items from queue to queue and also controls attention to processes.

4. The effective service rate depends on how control of item-handling and attention is accomplished.

It is important to understand that the control structure, implicit in the assumptions listed above, depends on GOALS -- set by the organization in the SIMCOPE context -- and operator training. If we view SIMCOPE as a real-world manned C^3 system, the control structure would be realized as a set of rules or conditions that define how processing is to be organized. The following conditions are presumed to hold for the SIMCOPE example:

C-1: Keep the Acknowledge queue empty.

C-2: Empty the Assign queue before working on reports.

C-3: Generating reports is a task that can be interrupted. But,

C-4: Operators must complete assignment of current information before moving on to acknowledge a new arrival (of a message).

Given these policies, t_{ACK}, the expected time to service a message in the Acknowledge queue, is the weighted average of two terms:

t'_{ACK}, the time-to-acknowledge when the server is actively working on the Acknowledge task; and

t_s, the time-to-switch to the Acknowledge task when a new message arrives with nothing in the queue.

The expected time-to-acknowledge, t_{ACK}, then is given by the following:

$$t_{ACK} = (1 - P_o)\ t'_{ACK} + P_o\ (t'_{ACK} + t_s) \qquad (8)$$

$$= t'_{ACK} + P_o\ t_s \qquad (9)$$

where P_o is the probability that the Acknowledge queue is empty (and $(1 - P_o)$ is the probability that the server is busy -- i.e., the queue is not empty). P_o still needs to be found. From Table 4-2 in Volume I:

$$P_o = 1 - \lambda_A/\mu_{ACK} \qquad (10)$$

$$= 1 - \lambda_A\ (t_{ACK}) \qquad (11)$$

which leaves

$$t_{ACK} = t'_{ACK} + (1 - \lambda_A\ t_{ACK})\ t_s \qquad (12)$$

or

$$(1 + \lambda_A\ t_s)\ t_{ACK} = t'_{ACK} + t_s \qquad (13)$$

and

$$t_{ACK} = (t'_{ACK} + t_s)/(1 + \lambda_A t_s) \quad . \tag{14}$$

Then

$$\mu_{ACK} = 1/t_{ACK} = (1 + \lambda_A t_s)/(t'_{ACK} + t_s) \tag{15}$$

is the effective service rate for the queue.

Effective Rates for the Assign and Report Queues

Recall that the Assign queue is considered only when the Acknowledge queue is empty. Therefore, service times will again be the weighted average of the two terms,

$$t_{ASN} = P_o \, t'_{ASN} + (1 - P_o) \, (t'_{ASN} + t_b) \tag{16}$$

$$= t'_{ASN} + (1 - P_o) \, t_b \tag{17}$$

where

$$t_b = 1/(\mu_{ACK} - \lambda_A) \tag{18}$$

is the expected time the Acknowledge process is busy, t'_{ASN} is the conditional time to assign given the process is active, and P_o the probability that the Acknowledge queue is empty. Hence,

$$\mu_{ASN} = \frac{1}{\left[t'_{ASN} + (1 - P_o) \, t_b\right]} \quad . \tag{19}$$

For the Report queue,

$$\mu_{REP} = \frac{1}{\left[t'_{REP} + (1 - P_{o_{ASN}}) \, t_{b_{ASN}}\right]} \tag{20a}$$

or

$$t_{REP} = t'_{REP} + (1 - P_{o_{ASN}}) \, t_{b_{ASN}} \tag{20b}$$

where $P_{o_{ASN}}$ is the probability of no messages in the Assign queue and $t_{b_{ASN}}$ is the expected busy period of the Assign queue:

$$P_{o_{ASN}} = 1 - \lambda_E/\mu_{ASN} \tag{21}$$

$$t_{b_{ASN}} = 1/(\mu_{ASN} - \lambda_E) \quad . \tag{22}$$

At this point, service rates and arrival rates have been derived for each queue in the system but since each still involves unknown parameters, the conditional service rates must be estimated.

A.3.2 Determine Service Rates for Performing Specific Tasks

The unknown parameters in the formula for the Acknowledge service rate are t'_{ACK}, the expected time required to perform the Acknowledge function when attention is already directed to Acknowledge, and t_s, the expected time required to switch attention to Acknowledge from some other function.

According to the SIMCOPE Subject Instructions (ALPHASCIENCE, 1984), the operator's task to acknowledge a message requires a single button press, an activity that should take approximately .5 seconds (Woodson, 1981). Therefore, let t'_{ACK} = .5 seconds.

If the Acknowledge queue is empty and a new message arrives, the subject's attention is drawn to the new message by either one or two cues. (Event messages and emergency status messages are accompanied by an audio alarm plus a flashing light; intelligence messages and routine status messages are cued with the flashing light only.) If we assume that only one reaction time ($\approx$ 0.2 seconds) is required for messages with audio alarms and 5.0 seconds are required for the rest, the expected switch time is

$$t_s = P_A \, (.2) + (1 - P_A) \, (5) = 5 - 4.8 \, P_A \quad , \tag{23}$$

where P_A is the proportion of messages accompanied by an audio alarm. If λ_{ES} is the arrival rate for emergency status messages and λ_{RS} is the rate for routine status messages (i.e., $\lambda_S = \lambda_{ES} + \lambda_{RS}$),

$$P_A = \frac{\lambda_{ES} + \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS}}{\lambda_I + \lambda_{ES} + \lambda_{RS} + \lambda_{ADS1} + \lambda_{ADS2} + \lambda_{BSS}} \quad (24)$$

and

$$P_A = (\lambda_{ES} + \lambda_E)/\lambda_A \quad . \quad (25)$$

(Recall that λ_A is the overall arrival rate for event-related messages, from expression #1 on p. 50.)

All parameters needed for the Acknowledgement process have been derived. However, the other major processes -- Assigning Event Data and Generating Reports -- still have unknown parameters that must be developed.

The Assign Queue Service Rate

There is only one unknown parameter associated with the Assign function, t'_{ASN}, the expected time to carry out the Assign task. In order to derive a service time for this task, one needs to identify subtasks required of the human operator, and their associated average durations. These subtasks must be analyzed to determine how service gets accomplished (in the queuing model).

> Again, this case illustrates how information from the IAT structural model (i.e., decomposition along the PROCESS dimension) becomes useful in estimating performance.

Figure A-4 describes the "Assign Event Number" process and identifies the subprocesses that would appear in an IAT structural decomposition. Bracketed numbers ("[ ]") indicate estimated times in seconds for each operation*; expressions denoted by "P" (such as P_O and P_E) describe branching probabilities.

Estimating Edit Time: How Operators Correct Errors in Assigning Event Data

With the exception of the Editing process, all of the operations shown in Fig. A-4 have associated completion times that are straightforward to derive from the SIMCOPE context. The time required to edit an assignment, t_E, can be estimated as follows.

*Based on SIMCOPE instructions (ALPHASCIENCE, 1984).

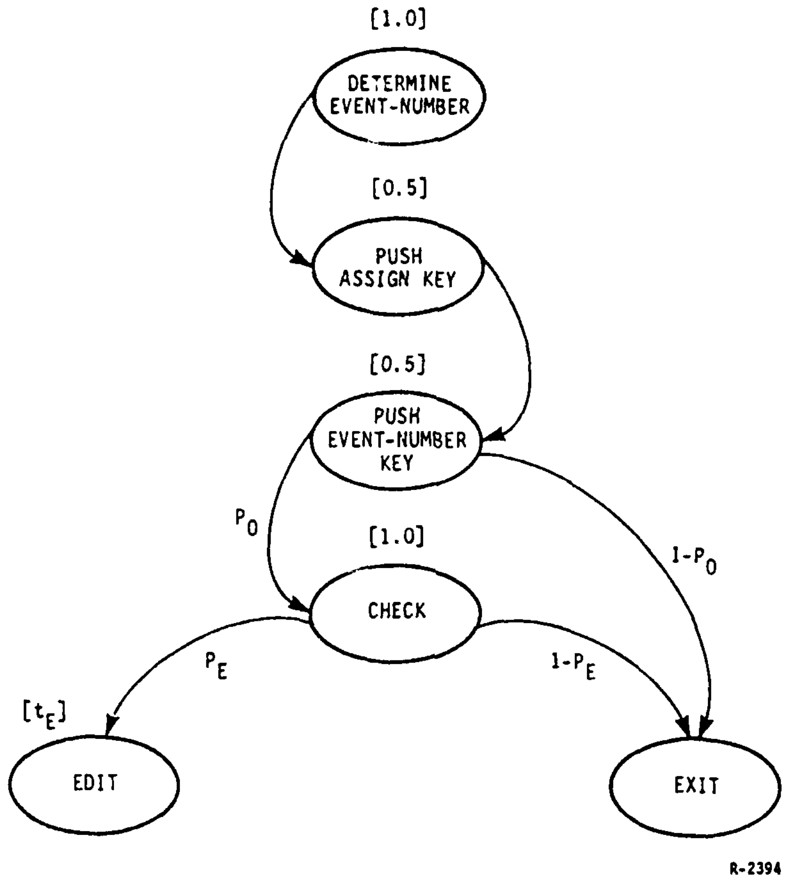


Figure A-4. The "Assign Event Number" Process.

From the SIMCOPE Subject Instructions:

1. There are two methods of editing --

   - Backstepping

   - Reassignment

2. Both methods are assumed to take .5 seconds each on the average.

3. Both are equally likely, once an operator has checked an assignment.

Figure A-5 illustrates the human operator decision and identifies the subprocesses that follow from the edit function.

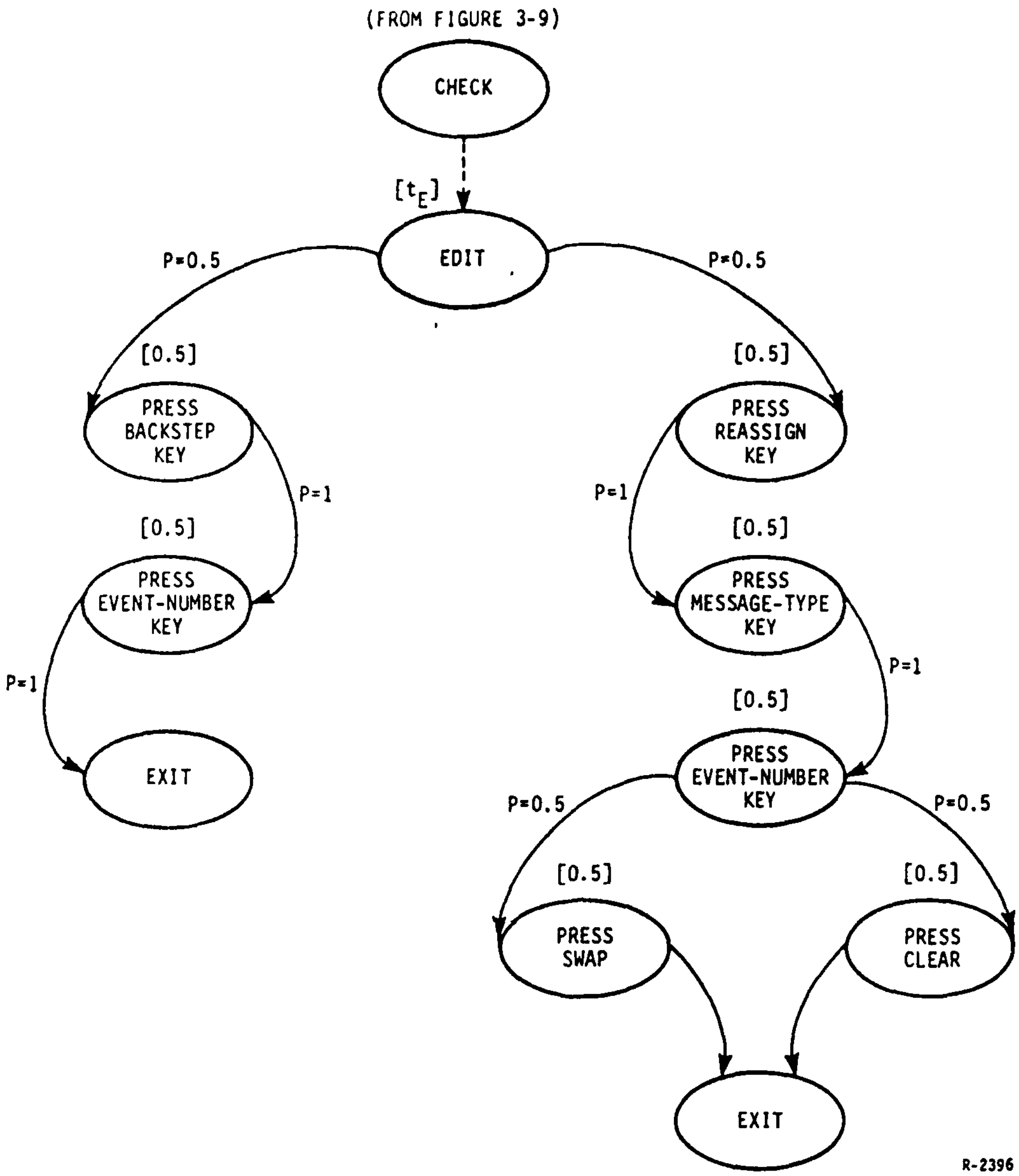


Figure A-5. Backstepping and Reassignment Processes -- How SIMCOPE Operators Correct Errors.

The expected edit time is

$$t_E = .5\left[[.5 + .5] + .5\,[.5 + .5 + .5 + .5 + .5\,[.5] + .5\,[.5]]\right] \qquad (26)$$

$$= .5\,[3.5] = 1.75 \text{ seconds}$$

where "[ ]" are used to indicate service time (in seconds) and non-bracketed numbers refer to branch probabilities (Fig. A-5).

Estimating Time for the Assign Process

Given t_E, it is now possible to estimate t'_{ASN}, the expected time to complete the entire "Assign" process. From Fig. A-4, it is clear that t'_{ASN} will be the sum of the times associated with each sub-process, [.5 + .5 + .5 + .5], plus P_O $(1.0 + t_E)$:

$$t'_{ASN} = 2.0 + P_O \, [1.0 + P_E \, (1.75)] \quad . \tag{27}$$

Estimating Time to Complete Reports (t'_{REP})

<u>(1) ADS-1</u> - The approach taken here is to consider reports for each message type, ADS-1, ADS-2, and BSS individually; then average the results to estimate t'_{REP}. Figure A-6 describes the sequence of processes that an operator would carry out for the ADS-1 report.*

Figures A-7, A-8, and A-9 present a process decomposition of the operations pictured on Fig. A-6. Decomposition is used for tasks judged subjectively to be more complex because of the decision-making that is required.

The last operation for completing the ADS-1 report is Edit, shown in Fig. A-10, where

1. P_{ED} = Probability the report is edited (requiring menu selection from a CRT display);

2. Each edit cycle is assumed to be 4.75 seconds long;

3. The probability that n-edit cycles will be performed is

$$P(n) = P_{ED}^{(n-1)} \, (1 - P_{ED}) \quad ; \tag{28}$$

and

4. The distribution for (28) has expected value

$$E(n) = 1/(1 - P_{ED}) \quad . \tag{29}$$

*We are assuming that an operator does NOT return to "Edit" after once leaving it.

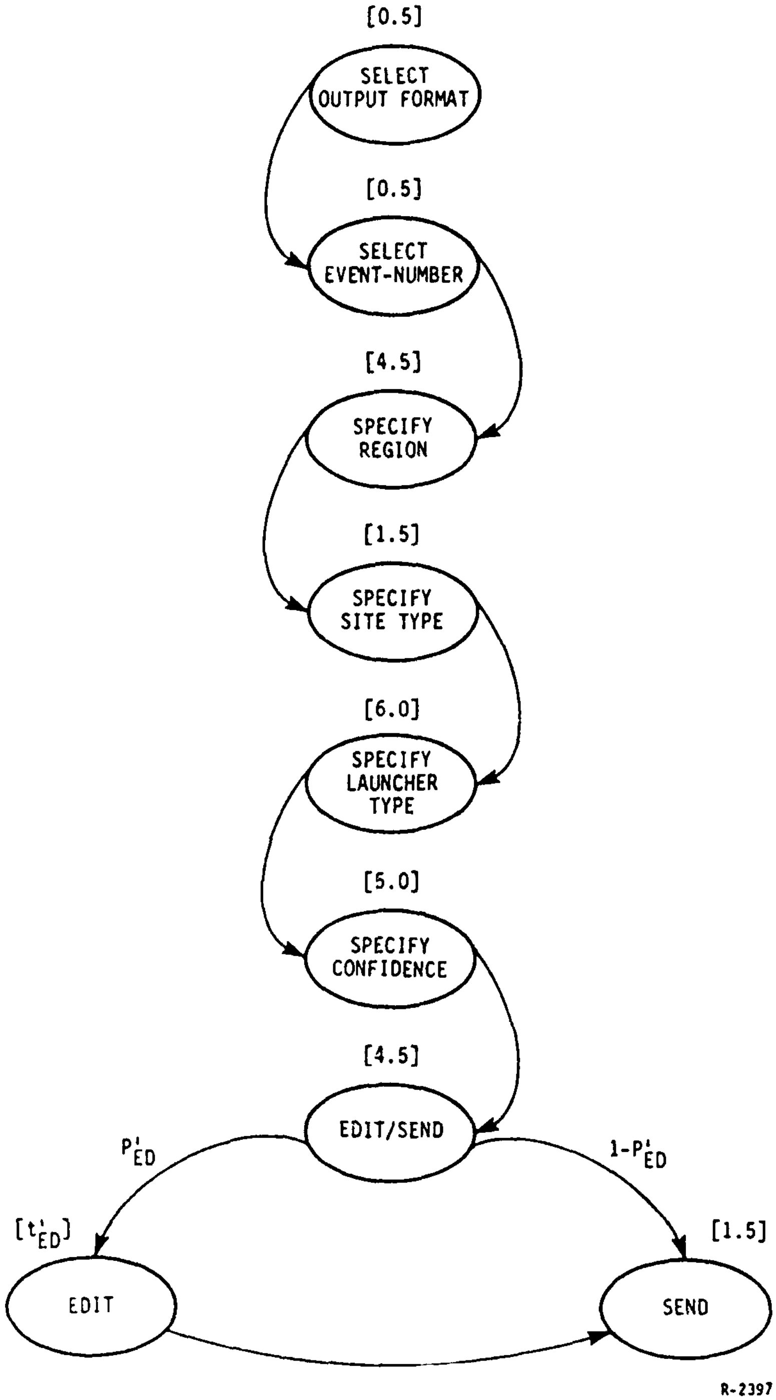


Figure A-6. The ADS-1 Report Sequence*

*This notation (i.e., ".../..." is used to designate a decision between two processes or courses of action, each of which is either decomposed further (e.g., "Edit," Fig. A-10) or terminates (e.g., "Send").

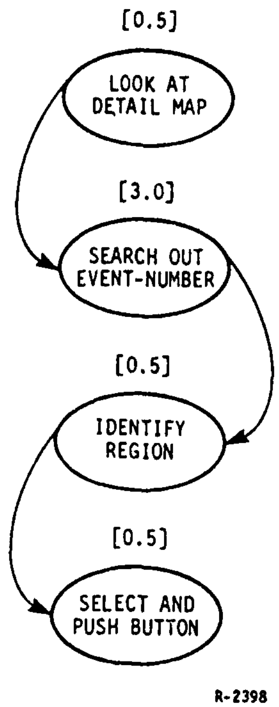


Figure A-7. Specifying the Region for ADS-1

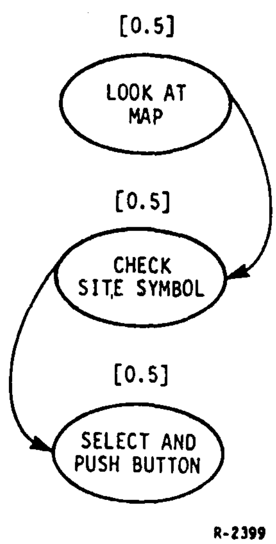


Figure A-8. Specifying Site-Type for ADS-1

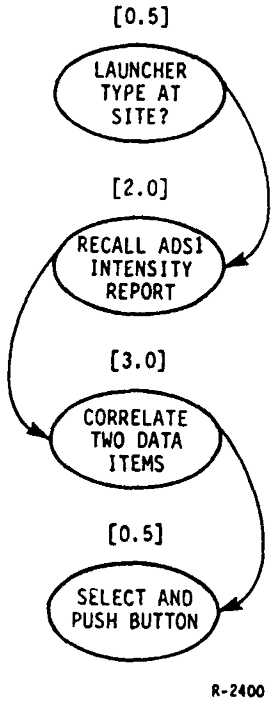


Figure A-9. Specifying Launcher-Type for ADS-1*

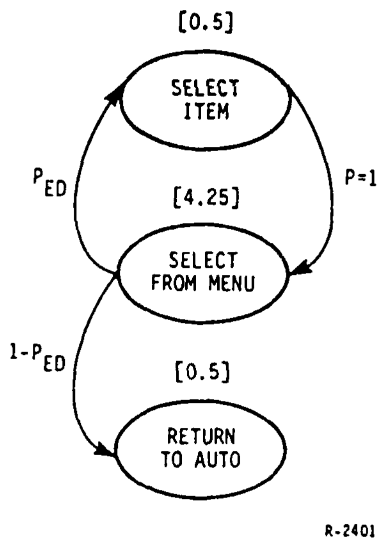


Figure A-10. Edit Sequence for ADS-1

*Note that this task sequence is assumed to involve operator decision-making. Although data were available within the SIMCOPE environment to describe the task "Specify Confidence" (shown in Figure A-6), data could not be obtained for specifying confidence of making the launcher-type decision. Hence, no sub-task called "Specify Confidence" is shown on Figure A-9, above.

From Fig. A-10 and the assumptions stated above describing the edit cycle, the expected time it would take to complete the Edit process is:

$$t'_{ED} = 4.75\ E(n) + .5$$

$$= \frac{4.75}{1-P_{ED}} + .5 \tag{30}$$

(where .5 represents the time needed to press the "AUTO" button).

Given the estimate of t'_{ED} above, we obtain the expected time to complete the ADS-1 report:

$$t'_{ADS-1} = 24.0 + P'_{ED} \left[\frac{4.75}{1-P_{ED}} + .5 \right] . \tag{31}$$

where P'_{ED} is the branch-probability that the report is edited;

P_{ED} is the probability an item is selected from a CRT menu, as part of the Edit sequence (shown in A-10);

and 24.0 (seconds) is the sum of the seven individual task completion times <u>plus</u> the time required to "Send," as shown in Fig. A-6.

<u>(2) ADS-2 and (3) BSS</u> - The approach for deriving completion times for the ADS-2 and the BSS reports is analogous. Figure A-11 shows estimated times for each operation involved in completing the ADS-2 report; Figs. A-12 and A-13 present decompositions of the more complex tasks required to generate the ADS-2 report (i.e., operations that require the operator to make more complex decisions).

Details of tasks required to complete the BSS report are presented in Fig. A-13; the possible-target decision is diagrammed in Fig. A-15. The logic for estimating times in these cases is identical to the previous example (for ADS-1):

$$t'_{BSS} = 10.5 + P'_{ED} \left[\frac{3.0}{1-P_{ED}} + .5 \right] . \tag{32}$$

where

1) t'_{ED} was obtained as in the ADS-1 sequence, and

2) P'_{ED} for ADS-1 and ADS-2 are the same;

$$t'_{ADS-2} = 17.5 + P'_{ED} \left[\frac{2.75}{1-P_{ED}} + .5 \right] . \qquad (33)$$

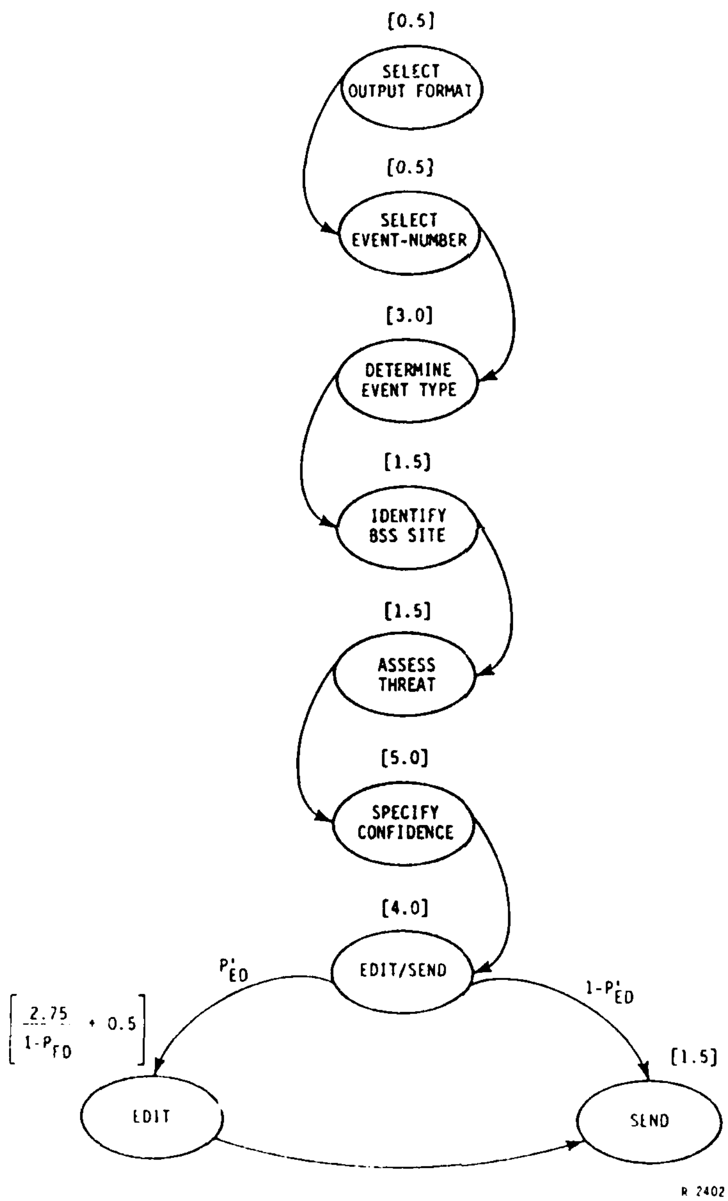


Figure A-11. ADS-2 Report Sequence

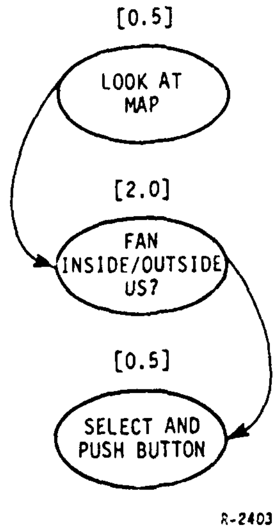


Figure A-12. Determine Event Type

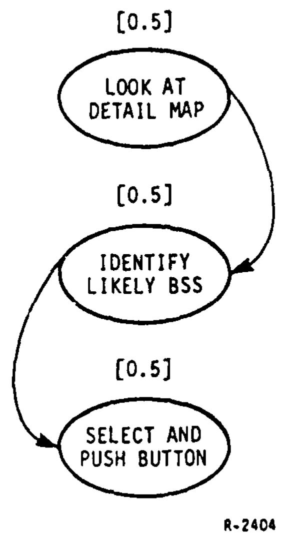


Figure A-13. Expected BSS

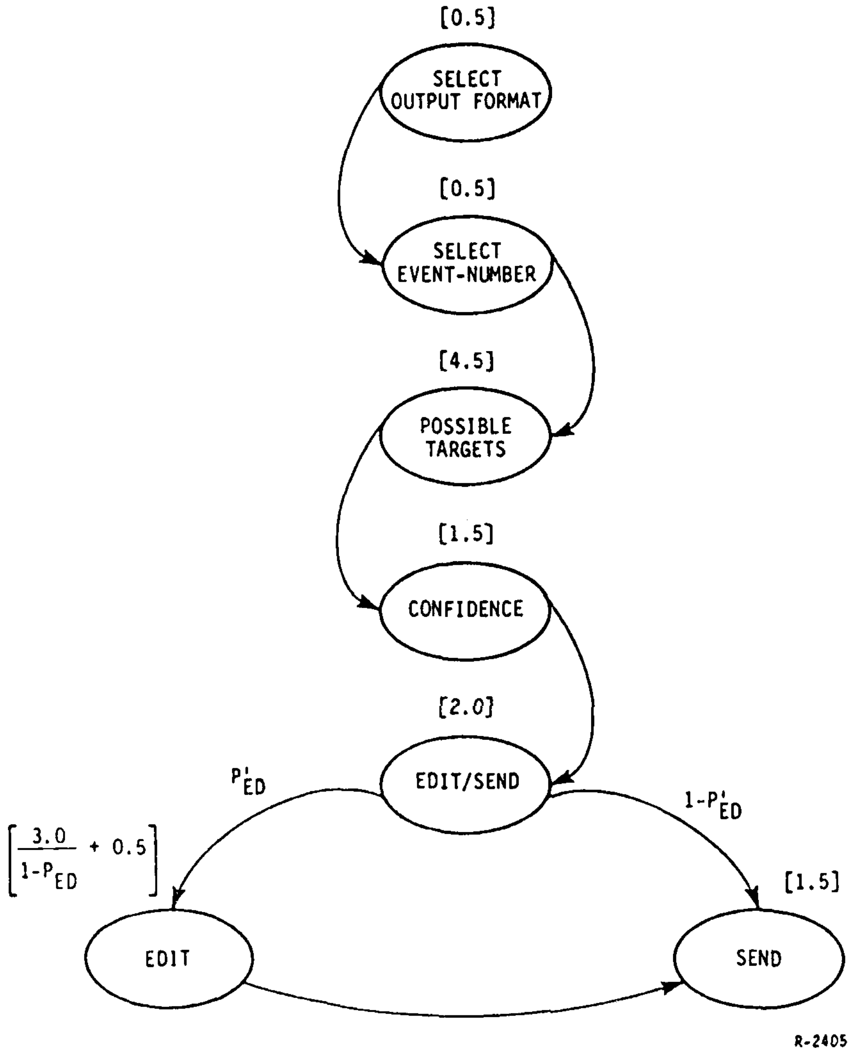


Figure A-14. BSS Decision Sequence

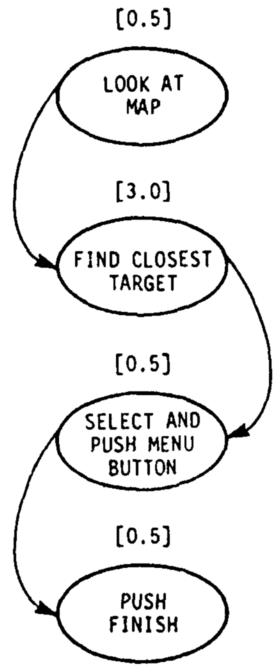


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Figure A-15. Possible-Target Decision

Predicting Overall Time to Generate Reports

The expected time to generate a report is the average of the times for each report type since there is generally one report of each type per suspected launch event:*

$$t'_{REP} = \frac{\left\{ 24.0 + P'_{ED}\left[\frac{4.75}{1-P_{ED}} + .5\right] + P'_{ED}\left[\frac{2.75}{1-P_{ED}} + .5\right] + 10.5 + P'_{ED}\left[\frac{3.0}{1-P_{ED}} + 5\right] \right\}}{3.0} = 17.5 + P'_{ED}\left[\frac{3.5}{1-P_{ED}} + 5\right] \tag{34}$$

i.e.,

$$t'_{REP} = \frac{t'_{ADS-1} + t'_{ADS-2} + t'_{BSS}}{3} .$$

*Assuming all launch events will intercept a region covered by BSS.

A.4 PREDICTING SIMCOPE HUMAN/SYSTEM PERFORMANCE: EFFECTS OF HEAVY AND LIGHT LOADING

In A.3.1 the following service time relationships were derived:

$$t_{ACK} = \frac{t'_{ACK} + t_s}{(1 + \lambda_A t_s)} \tag{35}$$

$$t_{ASN} = t'_{ASN} + (1 - P_o)\, t_b \tag{36}$$

$$t_{REP} = t'_{REP} + (1 - P_{o_{ASN}})\, t_{b_{ASN}} \tag{37}$$

where

$$P_o = 1 - \lambda_A t_{ACK}$$

$$t_b = \frac{t_{ACK}}{1 - \lambda_A t_{ACK}}$$

$$P_{o_{ASN}} = 1 - \lambda_E t_{ASN}$$

$$t_{b_{ASN}} = \frac{t_{ASN}}{1 - \lambda_E t_{ASN}} \quad .$$

Consider the Acknowledge time first. The estimate for the conditional Acknowledge time (t'_{ACK}) was 0.5 seconds and the switch time (t_s) was

$$t_s = 5.0 - 4.8 \left(\frac{\lambda_{ES} + \lambda_E}{\lambda_A}\right) \quad . \tag{38}$$

Therefore,

$$t_{ACK} = \frac{0.5 + 5.0 - 4.8 \left(\frac{\lambda_{ES} + \lambda_E}{\lambda_A}\right)}{1 + 5.0\, \lambda_A - 4.8\, (\lambda_{ES} + \lambda E)} \quad . \tag{39}$$

From these derivations, we can conclude the following about human/system performance in SIMCOPE:

1. The Acknowledge Process

As the proportion of audio-cued arriving messages increases, Acknowledge-time decreases.

Recall the events and emergency status messages are both cued (λ_{ES} and λ_E). This is due, in part, to the longer switch time associated with non-cued inputs. If λ_A is larger and if

$$\lambda_E + \lambda_{ES} \approx \lambda_A \quad ,$$

then

$$t_{ACK} \approx .52 \text{ seconds} \quad ,$$

which suggests that in such cases the Acknowledge process would not significantly slow processing.

If

$$\frac{\lambda_E + \lambda_{ES}}{\lambda_A} \approx 0 \quad ,$$

then

$$t_{ACK} \approx \frac{5.5}{1 + 5.0} \lambda_A$$

and

$$P_O = 1 - \frac{5.5 \lambda_A}{1 + 5.0 \lambda_A} \quad .$$

For λ_A large, P_O will be approximately zero, which means all resources will be consumed by Acknowledge. This suggests that this system could be subverted by flooding it with a large number of intelligence or routine system status messages.

2. The Assign Process

Consider the Assign process:

$$t_{ASN} = t'_{ASN} + (1 - P_o)\ t_b$$

$$= 2.0 + P_o\ [1 + P_E\ (1.75)] + (1 - P_o)\ \frac{t_{ACK}}{P_o}\ .$$

If the system is <u>heavily loaded</u> and the Acknowledge queue is nearly always occupied ($P_o \approx 0$), then t_{ASN} becomes very large, reflecting the fact that all resources are devoted to Acknowledge. If $P_o \to 1$, then $t_{ASN} = 3 + P_E\ (1.75)$, which is equivalent to parallel processing (i.e., separate servers for Acknowledge and Assign). Given that the service time penalty resulting from one operator is

$$\frac{(1 - P_o)\ t_{ACK}}{P_o}\ ,$$

it is straightforward to predict what benefits could be obtained by adding another operator.

3. The Generate Report Process

The estimated time for generating reports is:

$$t_{REP} = t'_{REP} + \left(1 - P_{o_{ASN}}\right) t_{b_{ASN}}$$

$$= 17.5 + P'_{ED} \left[\frac{3.5}{1-P_{ED}} + .5\right] + \lambda_E\ t_{ASN} \left(\frac{t_{ASN}}{1 - \lambda_E\ t_{ASN}}\right) .$$

Again the effects of heavy or light loadings can be easily explored. Assuming that the probability of editing is quite small ($P'_{ED} \approx 0$), then $t_{REP} = 17.5$ when the assignment queue is nearly empty ($t_{ASN} \approx 0$). This again is the limit that applies if parallel servers were used. The time multiplied by P'_{ED} could be used to evaluate the impact of poor versus good operators. For example, a good operator might have a small P'_{ED}, while a poor operator would have a larger value.

Once all parameter values are substituted, the time estimates are expressed as functions of the message arrival rates. Clearly, whether or not performance is adequate depends on this loading. The main point, however, is that such evaluation is quite easy to do once the appropriate expressions are obtained.

A.5 REDESIGN ISSUES

The analysis in this Appendix supports the following recommendations for system design:

1. Addition of One or More Operators --

   First-order effects of manpower changes can be explored by adjusting the appropriate service time parameters. To see the implications of these changes on the entire system, analysts can use components of the IAT structural model to trace (side) effects of staffing changes (RESOURCE allocation) on elements of ORGANIZATIONS, GOALS, and PROCESSES.

2. Change in Policy Concerning the Acknowledge Process --

   Recall that an excessive number of routine status or intelligence messages might overload the system. If only event or emergency messages are acknowledged, routine system status and intelligence messages are essentially eliminated for purposes of this analysis. In this case, $\lambda_{ES} + \lambda_E = \lambda_A$ and t_{ACK} would take on its lower bound value of

$$t_{ACK} = \frac{.52}{1 + .2\ \lambda_A} = \frac{.52}{1 + .2\ (\lambda_E + \lambda_{ES})} \ .$$

   An intermediate position would be to cue *all arrivals with an* alarm. This would eliminate the assumed 5-second delay associated with non-cued inputs and $t_A = .2$, so that

$$t_{ACK} = \frac{.52}{1 + .2\ \lambda_A} \ .$$

   The only difference in the two cases is the reduced arrival rate in the final case.

3. Redesign of Operator Display --

   From the decomposition of operator tasks discussed in A.3.2, it is apparent that button-pressing sequences directly affect the estimates of service time values. For example, consider the "region decision" required to generate the ADS-1 report (Fig. A-7). The operator must scan the map to find the appropriate launch site for the event under consideration. The search time might be reduced if this site were displayed with a blinking symbol. The blinking could reduce effective search time from 3.0 seconds to 1.0 second, which would produce approximately an 8 percent reduction for the ADS-2 report overall.

Although the examples cited above are based on a simulated (and simplified) C^3 system, they do suggest how sources of long delays can be isolated and design options considered for more realistic C^3 environments. As illustrated here, the analysis is done at a level that accounts for individual operator actions and decisions. Changes in procedures or the human-machine interface can then be directly addressed.

> Queuing theory can provide the means of integrating service and arrival time estimates into performance predictions -- but only when appropriate data can be collected from the operational environment and models are available to describe human behavior on tasks of a generic nature (e.g., scanning CRT displays).

A.6 REPRESENTATION BY PETRI NETS

It is a trivial exercise to represent these queuing equations by Petri nets, as discussed in Volume I. A more complex and more representative example is given in Section 4, which provides a five-level Petri-net decomposition of an Air Defense C^3 system.

APPENDIX B

NORAD CMC MWC/CP LITERATURE REVIEW

Documents furnished by AAMRL, listed in Table B-1, were reviewed and assessed for material relevant to the SLBM scenario. Tables B-2 through B-5 summarize high-level information gleaned from that review. Data voids were identified in an effort to specify areas where further information was needed to carry out quantitative analysis of human operator tasking. Specific questions were generated dealing with activations, terminations, and other time-dependent variables that would affect execution of MWC and CP functions. These questions, reproduced as Table B-6, were intended as representative issues, particularly sensitive to effects of real-world circumstances on crew activities and interactions. Table B-7 lists relevant acronyms.

TABLE B-1. AAMRL-SUPPLIED DOCUMENTATION

NO.	ORIGINATOR	CLASS.	TITLE	DATE
1	MITRE	S	NCS Missile Warning Summary	9 Aug 79
2	AAMRL	U	An Evaluation of Human Factors Engineering in the NORAD Missile Warning Center	1 Oct 80
3	SDC	S	NORAD C^3 Study: Command Post Data Flow	10 Oct 80
4	AAMRL	U	Human Factors Engineering in the NORAD Command Post	2 Apr 81
5	SDC	S	Integrated Analysis Techniques Development and Applications of $IDEF_0$ to NORAD Command Post Missile Event Operations	30 Sep 81
6	SDC	U	An Approach to the Identification of Functions Significant to the Performance of the NORAD Cheyenne Mountain Complex Mission	30 Nov 81
7	SDC	S	Integrated Analysis Techniques Development and Applications of $IDEF_0$ to NORAD Cheyenne Mountain Complex Operations	30 Nov 81
8	NORAD	S	Ivy League '82	15 Feb 82
9	SDC	S	NCMC Critical Event Data Flows	15 Jul 82
10	SDC	S	Critical Events/Conditions and Mission Threat Summary Report	5 Aug 82
11	SDC	S	NCMC Functional Analysis with Conclusions and Recommendations	30 Sep 82
12	SDC	U	Integrated Analysis Techniques (IAT) for Application to Command, Control, and Communciations Systems	30 Sep 82
13	SDC	U	NCMC Functional Analysis with Conclusions and Recommendations (Executive Summary)	15 Jan 83

(continued)

TABLE B-1. AAMRL-SUPPLIED DOCUMENTATION (Continued)

NO.	ORIGINATOR	CLASS.	TITLE	DATE
14	AAMRL	U	NORAD Command Post Replacement Phase 1 Report	28 Feb 83
15	AAMRL	U	Crew Options for a Mission Integrated NORAD Command Post	14 Jul 83
16	AAMRL	U	Survey of Human Factors Affecting the ADCOM Intelligence Center (ADIC) Watch Crew	15 Jul 83
17	AAMRL	U	Design Considerations for NORAD C^3 Displays	30 Sep 83
18	SDC	S	Functional Representation of the ADCOM Intelligence Center with NORAD Command Post Interfaces	15 Nov 83
19	SDC	U	Analysis of the CMC Displays	13 Apr 84
20	MITRE	U	NCCS Functional Analysis Charts (MITRE No. 843-3067)	15 Jun 84
21	MITRE	U	CSSR Message Processing Requirements (MITRE WP-6731)	Nov 84
22	NCMC	U	MWC Operations (J31 Operating Instruction 55-329)	14 Jan 85
23	AAMRL	U	Extracts from Unclassified Summary of AMRL Studies at NCMC (For Official Use Only)	[no date]

TABLE B-2. EXTERNAL DATA SOURCES

- NORAD Computer System (NCS) and Displays
- Space Defense Operations Center (SPADOC)
- SPADOC Computation Center (SCC)
- Air Defense Operations Center (ADOC)
- ADCOM Intelligence Center (ADIC)
- System Control (SC)
- Weather (WX)
- Emergency Action Resources
- Battle Staff Support Center (BSSC)
- Surveillance and Status Center (SSC)
- USAF Space Surveillance System NORAD
- Space Detection and Tracking System (SPADATS)

TABLE B-3. MWC PHASES OF OPERATION IN RESPONSE TO CRITICAL EVENTS

PHASE 1:	React to QUICK ALERT Indication(s)
PHASE 2:	Process Missile Event Messages
PHASE 3:	Assess System Confidence
PHASE 4:	Indicate NORAD Confidence Assessment to CINCNORAD

TABLE B-4. TEN GENERIC MISSILE WARNING CENTER PROCESSES (Table B-1, No. 2)

(1)	Monitor System Status and Performance
(2)	Monitor for Sensor Warning Indications
(3)	Interpret All Incoming Voice and Digital Data
(4)	Evaluate Implications of Interpreted Data
(5)	Decode Incoming Data and Encode Outgoing Data
(6)	Update System Database
(7)	Report Key System and Event Data
(8)	Coordinate Critical Missile Warning Functions
(9)	Maintain Console and System Configurations
(10)	Follow Established Procedures

TABLE B-5. PROCESSES FOR THREAT WARNING ASSESSMENT (Table B-1, No. 15)

(1)	Receive Event Indications
(2)	Monitor Sensor Status
(3)	Interpret Sensor Status/Capability
(4)	Verify Systems
(5)	Interpret Event Indications
(6)	Confirm Event Indications
(7)	Analyze Event Data (for Threat Characteristics)
(8)	Correlate Event Data (with Other External Data)
(9)	Formulate C^3 Decisions (with CINCNORAD)
(10)	Format Outputs
(11)	Transmit/Send

TABLE B-6. QUESTIONS ASKED ABOUT MWC/CP ACTIVITIES

1. Is flow of activities correct?

2. Where are we likely to find significant effects of reduced crew (under what circumstances)?

   - Day-to-day operations
   - Contingency
   - Crisis

3. To what extent does individual knowledge/skills/abilities (KSA) account for performance decrements if a given staff member is absent?

   (Example: If we asked operations personnel what would happen if the MWO or EVO were not there, would they say, "... it all depends who the person is filling those roles -- IAT RESOURCES as opposed to ORGANIZATIONAL elements.)

4. What specifically constitutes an EVENT?

   Do multiple missile launches always count as a single event? Under what circumstances?

   What are the implications for modeling single vs. multiple launches as events?

   - For Petri net modeling.
   - For queuing theory representations

5. To what extent is message-processing in the CP like SIMCOPE? [It is clear that the MWC does not accumulate messages in the same fashion as SIMCOPE. (Example: one message stream coming in to a single human operator.

6. How is message-processing implemented (what RESOURCES are used and how)? (Example: If phone lines are used, are they auto-dialers? If viewgraphs are put up on CCTV, how is that done/by whom, how long do such tasks take to complete?)

   - In MWC
   - In CP

   How are messages sent out of the NCMC?

   How/to whom does NCS broadcast?

(continued)

TABLE B-6. QUESTIONS ASKED ABOUT MWC/CP ACTIVITIES (Continued)

7. Assuming that the interval between the first message leaving NCMC and the last one is a relevant index of (CINCNORAD?) performance,

   How long does it take to get all messages out?

   How many messages are involved?

   If confirmation is requested, is it requested for each message (or part thereof), or for all messages at the same time?

   How do "altered" messages get sent out of NCMC (i.e., messages that get updated)?

   What triggers update (under what circumstances are messages changed)?

   What conditions does it take to change DEFCON levels?

   - How are DEFCON/LERTCON levels defined?
   - Are there any other levels/scales used to describe real-world status?

8. Is it the case that TW activities take place for less than 15 launches ... and AA for more than 15 launches?

   During AA, are the two message formats the only ones that get sent out? Or are they part of the TW phase?

9. When CINCNORAD requests confirmation or makes information requests via the CD to MWC, how is the querying carried out (e.g., beige loop, CRT, written communications, etc.)?

   What constitutes typical queries (viz., for each message format ... what questions would be asked to confirm alternative or options)?

   What is the impact on ongoing MWC operations when these questions are conveyed? How much time does it take to answer them?

TABLE B-7. LIST OF ACRONYMS

AC	Assistant for Communication
ACD	Assistant Command Director
AD	Assistant for Displays
ADCOM	Air Defense Command
ADIC	ADCOM Intelligence Center
ADOC	Air Defense Operations Center
BS	Battle Staff
BSSC	Battle Staff Support Center
CCT	Command and Control Technician
CD	Command Director
CDT	Command Director Technician
CINC	Commander-in-Chief
CINCLANT	Commander-in-Chief Atlantic
CINCPAC	Commander-in-Chief Pacific
CINCSAC	Commander-in-Chief Strategic Air Command
CP	Command Post
CSS	Command Systems Segment
GDC	Graphic Display Console
GDU	Graphic Display Unit
HQSAC	Headquarters Strategic Air Command
LCUDO	Launch Correlation Display Unit Officer
MEBU	Minimum Essential Back-Up Unit
MWC	Missile Warning Center
MWO	Missile Warning Officer
MWS	Missile Warning Supervisor
MWT	Missile Warning Technician
NCMC	NORAD Cheyenne Mountain Complex
NCS	NORAD Computer System
NID	Non-Interactive Displays
NMCC	National Military Command Center
NORAD	North American Aerospace Defense Command
SATPACK	Satellite Package
SCC	SPADOC Computation Center
SPADOC	Space Defense Operations Center
TTY	Teletype
TUDE	Teletype Users Data Entry
TW/AA(TWAA)	Threat Warning and Attack Assessment

APPENDIX C

NORAD MWC TASK DESCRIPTION WORKSHEETS

TASK DESCRIPTION WORKSHEET

1. TASK #13 - ESTABLISH BEIGE LOOP		2. PAGE 1 OF 1 PAGES
3. POSITION/S MWO/EVO/MWS (MWT KNOWLEDGE ONLY)	4. AFSC/S 20XX/276XX	
5. DATE 21 JUN 84	6. ANALYST/S CAPT CLARK, MSGT MATTHEWS, MSGT OGLE MSGT GLOVER, SSGT HAWORTH, LT HERRERA	7. PERSONNEL 100%
8. FREQUENCE OF PERFORMANCE DAILY	9. TASK CRITICALITY MAJOR	10. LEARNING DIFFICULTY EASY

NO	12.	SUB TASK/S	13. CUE	14. STANDARD	15. JOB AIDS
A	M/E/S	Respond to Beige Loop	When Beige Loop rings	IAW J31 OI 55-	Beige Phone J31 OI 55-
A1	M/E/S	Acknowledge that missile warning is on loop	After Command Post reports (BSSC if they are in place)		
A2	M/E/S	Copy information and acknowledge receipt			
B	M/E/S	Initiate Beige Loop	Initiation required		
B1	M/E/S	Pick up receiver			
B2	M/E/S	Declare "Missile Initiating"	After CP acknowledges		
B3	M/E/S	Pass info & close with "Missile Complete"			
B4	M/E/S	Hang up when CP releases conference			

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TASK DESCRIPTION WORKSHEET

1. TASK: #39 - PLOT COORDINATES

2. PAGE 1 OF 2 PAGES

3. POSITION/S: MWO/EVO/MWS/MWT

4. AFSC/S: 20XX/276X0

5. DATE: 11 JUN 84

6. ANALYST/S: CAPT CLARK/MSGT MATTHEWS/MSGT OGLE MSGT GLOVER/SSGT HAWORTH/LT HERRERA

7. PERSONNEL: 100%

8. FREQUENCE OF PERFORMANCE: DAILY

9. TASK CRITICALITY: MAJOR

10. LEARNING DIFFICULTY: EASY

NO	12. SUB TASK/S	13. CUE	14. STANDARD	15. JOB AIDS
A	ALL (U) Extract latitude and longitude from a sensor message	(U) Receive message containing coordinates	IAW Local procedure	
A1	ALL (U) Select proper map			(U) Maps
A2	ALL (U) Plot coordinates			(U) Maps
A3	ALL (U) Convert plotted position of lat/long coordinates to geographical location			(U) Maps
A4	ALL (U) Report findings to briefer			

TASK DESCRIPTION WORKSHEET

1. TASK	2. PAGE 1 OF 3 PAGES
#43 - (U) PROCESS SITE SYSTEM REPORT	

3. POSITION/S	4. AFSC/S
MWO/EVO/MWS/MWT	20XX/276X0

5. DATE	6. ANALYST/S	7. PERSONNEL
11 JUN 84	CAPT CLARK, MSGT MATTHEWS, MSGT OGLE, MSGT GLOVER, SSGT HAWORTH, CAPT HERRERA	100%

8. FREQUENCE OF PERFORMANCE	9. TASK CRITICALITY	10. LEARNING DIFFICULTY
ONCE PER SHIFT	CRITICAL	EASY

NO	12. SUB TASK/S	13. CUE	14. STANDARD	15. JOB AIDS
A	ALL (U) Copy site system report and amplifying information	(U) Receive site system report, after receiving site generated message	- IAW Checklist	(U) Phone, checklist, Plastic Sheets, Site Status Report Message
B	ALL (U) Verbally pass site system report info to briefer			
B1	ALL (U) Pass hardcopy site system report amplifying data to the briefer	(U) Receipt of amplifying data for site system report		
C	ALL (U) Call reporting sensor	(U) Receipt of msg requiring site sys report & haven't received call from site for 1 min		(U) Phone
C1	ALL (U) Implement site system reporting			
D	ALL (U) Repeat Steps A thru B1	(U) System report received but no site generated msg received at NORAD		
E	ALL (U) Initiate Voice Tell (See Task 52)	(U) When Voicetell is required.		

CLASSIFIED BY: MULTIPLE SOURCES
DECLASSIFY ON: OADR

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043 - KNOWLEDGE ITEMS

1. (U) Define site system report.

2. (U) Interpret hardcopy messages

3. (U) Identify time criteria for site system reporting.

4. (U) Identify use of applicable communications.

5. (U) Interpret console displays

6. (U) Identify criteria for reverse Voice Tell

APPENDIX D

PRELIMINARY NORAD MWC/CP ORGANIZATION FRAMES

In this appendix it is shown how the frame/slot data organization concept from artificial intelligence can be used to represent the NORAD Missile Warning Center/Command Post (MWC/CP) organizational, process, resource and goal interrelationships. Figure D-1 shows the lines of authority and responsibility among the various organizational elements.

Note that each frame represents a separate organizational element in the MWC. The slots in a frame represent the processes for which that element is responsible, the primary supporting resources, and the goal or objective to be achieved.

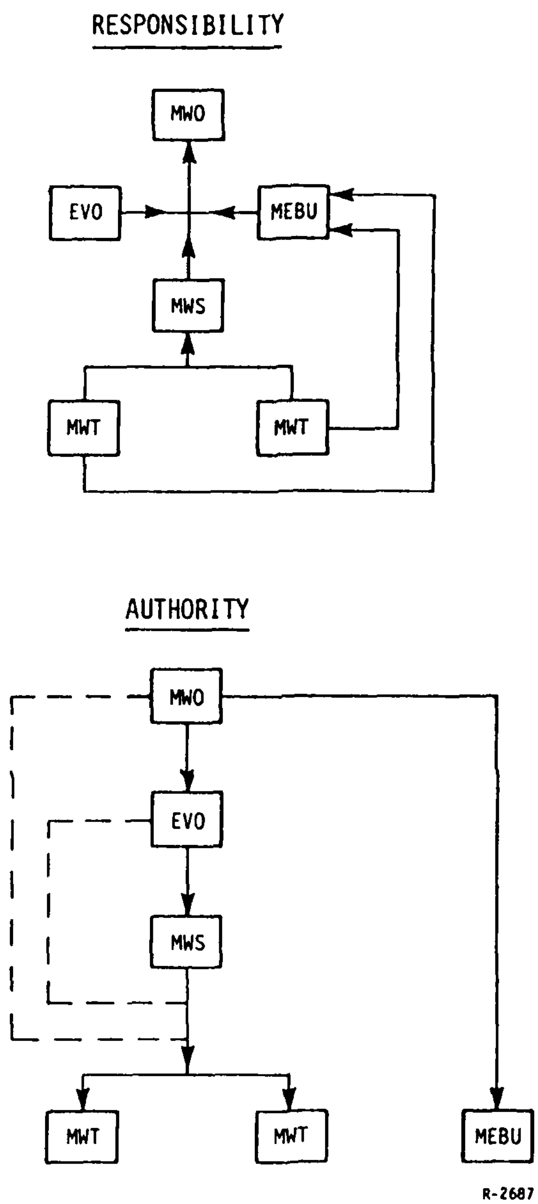

Figure D-1. Context: Organization Diagrams

ORGANIZATION NAME:	NORAD Command Post
GOAL:	Provide Threat Warning and Attack Assessment (to...)
PROCESS:	Aerospace Surveillance and Situation Assessment
PARENT ORGANIZATION:	USAF
ORGANIZATIONAL ELEMENTS:	CINC NORAD, Daily Duty Staff, Battle Staff
INPUTS:	MWC Missile Warning Center SPADOC Space Defense Operations Center ADOC Air Defense Operations Center ADIC Air Defense Command Intelligence Center BSSC Battle Staff Support Center
OUTPUTS:	TW/AA Messages*

*Messages leaving the NCMC CP are dispatched to members of an address list. The contents of that list may vary; the names of the variants and rules for list selection are needed.

ORGANIZATION NAME: Daily Duty Staff

GOAL: Peacetime Operations Fully Supported

PROCESS: Monitor for Threat Detection

PARENT ORGANIZATION: NORAD CP

ORGANIZATIONAL ELEMENTS:
CD - Command Director
CDT - Command Director Technician
ACD - Assistant Command Director
AC - Assistant for Communications
AD - Assistant for Displays
CCT - Command and Control Technician

INPUTS:
OUTPUTS:
Same as Parent

ORGANIZATION NAME:	Battle Staff (BS)
GOAL:	Wartime Operations Fully Supported
PROCESS:	Provide Support to CINC NORAD
PARENT ORGANIZATION:	NORAD Command Post (CP)
ORGANIZATIONAL ELEMENTS:	CINC - Commander-in-Chief D/CINC - Deputy Commander-in-Chief NCOC - NORAD Computer Operations Center Commander CMDR ASST - Assistant NORAD Computer Operations Center Commander EAO - Emergency Actions Officer(s) VCMDR ADCOM - Vice Commander, Air Defense Command J2 - Intelligence J3 - Operations J4 - Logistics J6 - Communications
INPUTS:	
OUTPUTS:	

ORGANIZATIONAL ELEMENTS:	Command Director (CD)
GOAL:	CP Functions Executed Successfully
PROCESS:	1) Supervise and Direct NCMC Operations 2) Represent CINCNORAD in his absence
PARENT ORGANIZATION:	NCMC
SUBORGANIZATION:	Daily Duty Staff
INPUTS:	<u>Messages or Requests to/from CINCNORAD</u> Specific Digital Data Voice Communication (Secure/Unsecure and External/Internal) Non-Vocal Signals Threat Panel Displays Large Screen Displays
OUTPUTS:	<u>Directives to CP Staff; inquiries; reports</u> Digital Data Voice Communication Non-Vocal Signaling Other Keyboard/Switch Actions
PRIMARY RESOURCES:	1) CD Console 2) CP Staff 3) NCMC Support Centers
RELATED RESOURCES:	Regulations/Directives Doctrine/Orders Operating Instructions/Technical Orders Procedures Guides/Handbooks Checklists/Message Formats Training Courses/Exercise Materials

ORGANIZATIONAL ELEMENT:	Command Director Technician (CDT)
GOAL:	All Messages Dispatched
PROCESS:	Authenticator Control and Alert Message Dissemination
PARENT ORGANIZATION:	Daily Duty Staff
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Assistant Command Director (ACD)
GOAL:	CD Supported
PROCESS:	Backup CD and Implement Emergency Action Procedures
PARENT ORGANIZATION:	Daily Duty Staff
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Assistant for Communication (AC)
GOAL:	Personnel Recalled, Events Tracked, and Log Maintained
PROCESS:	Establish JCS Alerting Network Communications and Record Activities
PARENT ORGANIZATION:	Daily Duty Staff
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Assistant for Displays (AD)
GOAL:	CP Properly Briefed, Authentication System Inventoried and Log Maintained
PROCESS:	Organize and Maintain Non-Computer Information Base
PARENT ORGANIZATION:	Daily Duty Staff
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Command and Control Technician (CCT)
GOAL:	AC Supported
PROCESS:	
PARENT ORGANIZATION:	Daily Duty Staff
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Missile Warning Center (MWC)
GOAL:	Missile Event Data Reported
PROCESS:	Monitor System Status and Process Site Messages
PARENT ORGANIZATION:	NCMC
SUBORGANIZATION:	MWO Missile Warning Officer EVO Events Verification Officer (formerly Events Analysis Officer) MEBU Technician (formerly CCPDS Officer) MWS Missile Warning Supervisor (formerly Superintendent NCS) MWT Missile Warning Technicians (two) (formerly E/W Hemisphere Monitors)
INPUTS:	GDU Changes Terminet Printer Output MEBU Console Changes Tactical Display Panel Changes Auditory Alarms Telephone Messages
OUTPUTS:	TUDE Equipment TTY Messages Telephone Messages
RELATED RESOURCES:	Maps Checklists

ORGANIZATIONAL ELEMENT:	MEBU Technician
GOAL:	Database Updated; Accessed on NCS
PROCESS:	Operate MEBU Equipment or GDU Failure
PARENT ORGANIZATION:	Missile Warning Center
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Missile Warning Supervisor (MWS)
GOAL:	Directives Complied with for All Actions Accomplished
PROCESS:	Supervise MWT Crew and Accomplish Assigned Activities
PARENT ORGANIZATION:	Missile Warning Center
SUBORDINATE ORGANIZATIONAL ELEMENTS:	Missile Warning Technicians (Two)
INPUTS:	
OUTPUTS:	
RESOURCES:	

ORGANIZATIONAL ELEMENT:	Missile Warning Technician (MWT)
GOAL:	Database Maintained and Communications Accomplished
PROCESS:	Operate GDU Console and Backup MEBU Technician
PARENT ORGANIZATION:	Missile Warning Center
SUPERVISORY ELEMENT:	MWS
SUB ORGANIZATIONS:	N/A
INPUTS:	
OUTPUTS:	
RESOURCES:	

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U.S. GOVERNMENT PRINTING OFFICE 1988